Physical fitness and health-related quality of life in pediatric renal transplant recipients: An interventional trial with active video gaming

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Background: Pediatric renal transplant recipients are at increased risk for cardiovascular diseases, one contributing factor is reduced cardiorespiratory fitness. The purpose was to evaluate cardiorespiratory fitness, motor coordination, muscle strength, daily physical activity, and health-related quality of life and to find out, if active video gaming is effective for improving these items in this patient population.

Methods: Twenty renal transplant recipients (13.5 ± 3.4 years) and 33 matched healthy controls (13.1 ± 3.2 years) performed a spiroergometry, a motor coordination test, and a maximal handgrip strength test. Quality of life was determined with a validated questionnaire, and daily physical activity was recorded with a physical activity monitor. Thirteen patients (12.9 ± 3.4 years) participated in a 6-week home-based exergaming intervention (3×/week for 30 minutes) and repeated all tests after that.

Results: The renal transplant recipients exhibited a substantial impairment compared with the controls in peak oxygen consumption (−31%, \( P < .001 \)), motor competence (−44%, \( P < .001 \)), daily physical activity (−33%, \( P = .001 \)), and quality of life (−12%, \( P = .017 \)). Handgrip strength was similar in both groups. Despite of low compliance in the intervention group, steps per hour were significantly increased after 6 weeks of exergaming (+31%, \( P = .043 \)); however, all other measures remained unchanged.

Conclusion: Cardiorespiratory fitness, motor competence, and quality of life are reduced in pediatric renal transplant recipients. Home-based exergaming is not appropriate to improve these items, probably due to a substantially impaired motor competence. However, it provided a stimulus for an increased daily physical activity.

Keywords: cardiorespiratory fitness, exergames, health-related quality of life, motor coordination, physical activity
Renal transplantation is the preferred treatment for pediatric end-stage renal disease and has improved life expectancy and quality of life of these young patients. However, patients who underwent renal transplantation during childhood are at increased risk for metabolic and cardiovascular diseases such as obesity, dyslipidemia, diabetes mellitus, and hypertension, probably at least partly due to insufficient regular physical activity and reduced fitness.\(^1\) For example, in an investigation of Akber et al,\(^1\) only 10% of the male and 5% of the female patients with chronic kidney disease (7-20 years of age) met the recommendations for these age groups of 15 000 and 12 000 steps per day, respectively.\(^8\) Lifestyle modifications including an increase of physical activity are of utmost importance for improving the outcome after pediatric renal transplantation.\(^9,10\) To date, only few studies investigated the beneficial effects of an exercise intervention in renal transplanted subjects,\(^10-13\) and to the best of our knowledge, only one study focused on an increased physical activity and cardiorespiratory fitness in TX.\(^10\)

Recently, the use of active video games has been reported to be a feasible and effective method to improve regular physical activity, physical fitness, cardio-metabolic health, and health-related quality of life in children and adolescents with various health problems.\(^14-19\) Active video gaming can also be used for home-based exercise programs. For TX who often live at some distance to the renal transplantation outpatient clinic, home-based exercise intervention might be better suited than center-based programs. In overweight adult patients with chronic kidney disease, a home-based exercise program was as effective as center-based training for the improvement of physical fitness and health-related quality of life.\(^20\)

The primary aim of the present study was to investigate the cardiorespiratory fitness, muscle strength, motor coordination, daily physical activity, and health-related quality of life of TX in comparison with CON (cross-sectional study). The secondary aim was to find out whether a home-based exercise intervention with the use of active video gaming is an appropriate tool for improving physical capacity and health-related quality of life in this patient population. Therefore, a subgroup of the cross-sectional study was subjected to an exercise program with the Wii fit console of Nintendo\(^\circledR\). We hypothesized that 6 weeks of regular exergaming could initiate an increased general daily physical activity and

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**FIGURE 1** Flowchart of recruiting and analyzing pediatric renal transplant recipients and healthy controls. n, sample size; t1, first baseline testing; t2, second baseline testing (immediately prior to intervention); t3, testing after active video game intervention; yr, years of age
would improve the impaired fitness in these young renal transplanted patients.

2 | MATERIALS AND METHODS

2.1 | Participants

2.1.1 | Pediatric renal transplant recipients

At study initiation, 83 children and adolescents regularly attended the renal transplantation outpatient clinic of the University Children’s Hospital Heidelberg. Exclusion criteria for participation in the present study were (a) age <8 or >21 years, (b) necessity of hemo- or peritoneal dialysis, (c) serious cardiovascular diseases (eg, cardiac arrhythmia), (d) musculoskeletal or neurological disorders, and (e) cognitive limitations. Forty-eight of 83 (58%) TX were eligible for this study. Twenty-one of these 48 patients (44%) agreed to participate in the baseline evaluation, which consisted of exercise tests, activity screening, and a validated questionnaire for evaluating health-related quality of life by the use of the PedsQL™ 4.0.21 One patient left the study after the first tests, leaving 20 patients (16 males and 4 females; TX) for further evaluation. Thirteen patients (9 males and 4 females; TXwii) agreed to participate in the second part of this trial, which consisted of a 6-week home-based exercise intervention using a Wii fit video game console of Nintendo® (Figure 1).

2.1.2 | Healthy controls

Thirty-three CON (25 males and 8 females; CON) from various local schools agreed to participate in the first part of this trial (cross-sectional study) and completed the exercise tests, the activity screening, and answered the PedsQL™ 4.0 questionnaire. The principle aim was to match two healthy controls with one renal transplanted patient. Matching criteria were sex, pubertal stage, attended type of school, and regular physical activity per week, which were assessed by a semi-quantitative telephone interview. Although two healthy control subjects could not be recruited for each pediatric renal transplant recipient (TX, n = 20; CON, n = 33), the groups were well comparable regarding the matching criteria.

Based on the information about regular physical activity provided by the participants and their parents within a personal interview, the study participants were stratified into the following subgroups: (a) no physical activity besides physical education, (b) low (or no regular) physical activity, and (c) moderate physical activity, that is, more than once per week.

The study was approved by the local Ethics Committee (S-043/2015) and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all parents/guardians, with assent from patients when appropriate for their age.

2.2 | Study design

All participants were subjected to cycling or treadmill spiroergometries, motor coordination, and handgrip strength tests. To minimize habitual effects, these tests were performed twice (t1 and t2). For spiroergometry data, mean values of the two baseline measurements t1 and t2 were used for statistical analyses. Because of expected learning effects for motor coordination and maximal handgrip strength, only the results of t2 were used as baseline values for TX and CON, respectively. Furthermore, at t1, activity of daily life (steps per hour) was evaluated with a SenseWear® device (BodyMedia®) and health-related quality of life was assessed with PedsQL™ 4.0. In the TXwii subgroup, all examinations were repeated after the Wii fit intervention (t3) described below.

At each investigation date (t1-t3), the participants’ weight and height were measured. Weight, height, and BMI were converted to Z-score values related to age- and gender-specific means and SD of European reference populations.22,23 Systolic and diastolic blood pressures were derived from casual blood pressure measurements by sphygmomanometer and converted to age- and gender-specific Z-score values based on reference data from a large national trial.24 Furthermore, a 12-lead resting ECG was recorded. In the TX cohort, serum creatinine for the eGFR25 was determined within the routinely performed blood tests at the renal transplantation outpatient clinic. No blood samples were taken from CON.

2.3 | Spiroergometry

To assess cardiorespiratory fitness, a spiroergometry was performed on an electronically braked cycle ergometer (Corival, Lode BV Medical Technology) or in small children on a motorized treadmill (Quasar med, h/p/cosmos®). On the cycle ergometer, the exercise test started with 20 W and load was increased by 10 W every minute until volitional exhaustion, followed by 5 minutes of recovery with 20 W. The ergometer seat could not be adapted for small children (ie, body height <135 cm; TX, n = 3; TXwii, n = 1; CON, n = 5). Therefore, these small children performed a walking treadmill test at an individually chosen speed starting with a treadmill inclination of 1%, which was increased by 1% every minute until volitional exhaustion.

VO2, carbon dioxide release (VCO2), and VE were measured continuously with a breath-by-breath spirometry system (Geratherm®) and the corresponding software Blue Cherry (version 1.2.2.16) using an individual adjusted face mask. Before each test, both sensors were calibrated with known gas concentrations and the flowmeter with a 3L-syringe according to the manufacturer’s instructions. A 12-lead ECG was continuously recorded during the exercise test using the Amedtec ECPro software (version 4.21.0) and self-adhesive electrodes. Peak oxygen uptake (VO2peak) and RERpeak were detected as the highest 30 seconds average values at the time of volitional exhaustion. Ventilatory thresholds were identified with the V-slope method (VT1) and as respiratory compensation point (VT2).26 One TX patient did not tolerate the spirometry face mask and
thus completed a treadmill ergometry instead. In TX\textsubscript{Wii}, spirometry data were available for 11 of 13 patients because of two measurement errors at t3.

2.4 | Motor coordination test

Motor coordination level was checked with a motor coordination test for children and adolescents comprising the four motoric tasks balancing backwards, jumping on one leg, jumping side to side, and shifting platforms. All tasks were executed according to the procedure described in detail by Kiphard and Schilling\textsuperscript{27} Four age- and sex-related MQs were determined and transformed into one final MQ\textsubscript{total}. Kiphard and Schilling\textsuperscript{27} identified five levels of motor coordination. Final MQs ≤70 correspond to a disordered motor coordination level and MQs from 71 to 85 to an alarming motor coordination level, while values from 86 to 115 indicate a normal, ≥116 a good and ≥131 a very good level.

2.5 | Maximal handgrip strength

Handgrip strength was measured with a hydraulic Jamar\textsuperscript{®} hand dynamometer (Sammons Preston). Participants executed the test while standing straight and bending the operating arm at a 90° angle. Arms were held tight to the trunk. The handle could be adjusted to participants’ hand size, so most of the tested children and adolescents used the smallest settings 1 and 2, and some of the older participants used setting 3. Maximal handgrip strength was determined out of three maximal attempts with the non-dominant forearm. Maximal handgrip strength could not be measured in one TX patient.

2.6 | Daily physical activity

Daily physical activity was recorded for at least 5 consecutive days at t1 and for TX\textsubscript{Wii} additionally at t3 using a SenseWear\textsuperscript{®} device (BodyMedia\textsuperscript{®}). The SenseWear\textsuperscript{®} armband was placed at the upper arm of the non-dominant side and was prepared individually before recording. Only measurements with at least two consecutive days of recording and at least 12 hours of patients being awake, respectively, were included for data evaluation. Recorded data were evaluated using the SenseWear\textsuperscript{®} Professional software (version 8.1). The mean values of steps per hour, instead of steps per day, were calculated because of the wide inter-individual variation in the participants’ time of being awake. To identify outlier days, participants were asked to keep an activity diary while wearing the SenseWear\textsuperscript{®} device. One TX patient refused to wear the SenseWear\textsuperscript{®} armband.

2.7 | Health-related quality of life

To determine health-related quality of life, TX and CON were asked to answer the PedsQL\textsuperscript{®}, version 4.0 Generic Core Scales at baseline (t1) and for TX\textsubscript{Wii} additionally at t3. The PedsQL\textsuperscript{®} 4.0 consists of 23 items to assess physical, emotional, social, and school functioning of children (8-12 years), adolescents (13-18 years), and young adults (18-25 years). The total maximum score could be 100 for the whole questionnaire and every subscale.\textsuperscript{28} In this regard, a higher score corresponds to a higher level of health-related quality of life. Because one of the patients had serious problems in understanding the PedsQL\textsuperscript{®} 4.0 items linguistically and substantively, only 19 questionnaires could be evaluated to identify the child/teen reported overall score.

2.8 | Wii fit intervention

For the second part of the investigation, a Nintendo\textsuperscript{®} Wii game console including a balance board and the Wii fit DVD were allocated to the renal transplanted subgroup TX\textsubscript{Wii} for 6 weeks. The young patients were instructed to practice 3 × 30 minutes per week at home and were asked to record their heart rate, measured by a provided heart rate monitor (Polar FS1C) as well as their perceived exertion using a Borg Scale\textsuperscript{29} after each exercise bout. Furthermore, they were contacted regularly via email or phone by the investigators and were asked to return the activity protocol. Intervention compliance was rated based on the completeness and returning of the practicing protocols. Compliance was interpreted as good, if the patients exercised more than half of the required practicing time.

2.9 | Statistical analysis

All statistical tests were processed using SPSS Statistics for Windows, version 24.0 (IBM Corp.). Figures were created with GraphPad Prism, version 5.01 for Windows (GraphPad Software). Comparability of TX and CON concerning the matching criteria sex, pubertal stage, attended type of school, and regular physical activity was tested using the chi-square test. t Tests for independent samples were calculated to check significant differences between TX and CON. Because normal distribution was missing for absolute VO\textsubscript{2peak} and overall score PedsQL\textsuperscript{®} 4.0, differences were tested using the Mann-Whitney U test. To assess effects from pre- to post-intervention in TX\textsubscript{Wii}, t tests for dependent samples were calculated for all parameters except absolute VO\textsubscript{2peak} (Wilcoxon’s test). Because of small sample sizes, no statistical tests were calculated for subgroups relating to regular physical activity and intervention compliance. As this is an exploratory trial, P-values have no confirmatory value, but will be considered significant (\textit{P} < .05) in descriptive manner. Table data are presented as mean ± SD. Box plots concerning the comparison of TX and CON show medians and whiskers as minimum to maximum. Floating bars, to present the relative changes from pre- to post-intervention in TX\textsubscript{Wii} show lines as median and the bars range from minimum to maximum.
3 | RESULTS

3.1 | Anthropometric and health-related data

Anthropometric and health-related data for TX, TX\textsubscript{Wii}, and CON are presented in Table 1. There were significant differences between TX and CON concerning the height Z-score \((P = .003)\) as well as BMI \((P = .029)\) and BMI Z-score \((P = .043)\), while all other anthropometric and health-related parameters were similar in both groups. All TX patients received immunosuppressive medication, 17 of 20 glucocorticoids. Additionally, 17 of the kidney-transplanted patients were treated with antihypertensive drugs and 8 of them with beta blockers.

3.2 | Compliance during exercise intervention

Based on the heart rate records and the information about perceived exertion, only 5 patients out of the 13 TX\textsubscript{Wii} performed the intervention exercises as required and were identified as well compliant. Heart rate during aerobic and strengthening exercises with the Wii console of the well-compliant subgroup was approximately 65% of the peak heart rate measured in the spiroergometry tests before the exercise intervention. Overall perceived exertion rated with a Borg Scale\textsuperscript{25} was 10.9 (range 8.5-12.5) which is defined as a fairly light effort.
3.3 | Cardiorespiratory fitness

3.3.1 | Cross-sectional study

In TX, relative VO$_{2peak}$ was significantly reduced by 31% on average (Table 2) and relative peak power output showed a significant average reduction by 37% compared with CON (1.9 ± 0.5 W·kg$^{-1}$ vs 3.0 ± 0.5 W·kg$^{-1}$; $P < .001$; Figure 2A and 2B). A significant lower (21%) VE$_{peak}$ was observed in TX compared with CON (Table 2). An average RER$_{peak}$ of 1.11 in TX and CON indicated a high effort in both groups toward volitional exhaustion. Peak heart rate was significantly lower in TX than in CON (Table 2). Furthermore, significant differences were observed between TX and CON for VO$_2$ and heart rate at the ventilatory thresholds (Table 2). While VO$_2$ related to VO$_{2peak}$ was similar in both groups at these thresholds, VO$_2$ per kg body weight at VT1 and VT2 was significantly reduced in TX compared with CON by 35% and 32%, respectively. Also, heart rate at VT1 and VT2 was significantly lower in TX than in CON. Regarding the participants’ regular physical activity per week, there were tendencies for VO$_{2peak}$ and peak power output to be increased in subjects with a higher physical activity level in both groups (Figure 2A and 2B).

3.3.2 | Exercise intervention

After 6 weeks of active video gaming, absolute values of VO$_{2peak}$ and peak power output remained unchanged (Figure 3A and 3D). Related to body weight, there was even a significant average reduction by 7% in VO$_{2peak}$ (Table 2). Peak values for RER, VE, and heart rate did not change significantly. VO$_2$ related to VO$_{2peak}$ at both ventilatory thresholds was similar before and after intervention. However, a significant decrease in VO$_2$ at VT2 and a tendency for decrease ($P = .076$) in VO$_2$ at VT1 were observed after the exercise intervention by 7% and 11% on average, respectively. Heart rate at VT2 also tended toward a decrease ($P = .085$; Table 2). With regard to the compliance in TX, a decrease in VO$_{2peak}$ and peak power output, especially related to body weight, was observed in patients with low compliance, whereas VO$_{2peak}$ and peak power output was maintained in complying patients (Figure 3A, 3D).

3.4 | Motor coordination

3.4.1 | Cross-sectional study

TX showed significantly reduced levels of motor coordination compared with CON ($P < .001$). The mean total MQ of TX (59.7 ± 17.5) corresponded to a disordered motor coordination level, while CON reached normal motor coordination levels (MQ$_{total} = 105.8 ± 14.9$). With regard to regular physical activity per week, TX with higher activity levels showed higher levels of motor coordination than inactive patients, but did not yet reach motor coordination levels of the CON subgroups (Figure 2C).

3.4.2 | Exercise intervention

Regardless of the intervention compliance, there was no change of motor coordination after 6 weeks of active video gaming (Figure 3B).

3.5 | Maximal handgrip strength

3.5.1 | Cross-sectional study

No significant difference between TX and CON was found for maximal handgrip strength. There was a tendency for a greater handgrip strength in moderately active subjects in both groups (Figure 2D).

3.5.2 | Exercise intervention

After intervention handgrip strength remained unchanged in all of TX (Figure 3E).

3.6 | Daily physical activity

3.6.1 | Cross-sectional study

On average, CON did 229 steps per hour more than TX, the difference being significant ($P = .001$). However, no tendency could be observed regarding the self-reported physical activity per week in both groups (Figure 2E).

3.6.2 | Exercise intervention

After 6 weeks of active video gaming, daily physical activity of TX was significantly ($P = .043$) increased by 121 steps per hour (approximately 31%; Figure 3C). The average improvement of daily physical activity could be observed for both, the low and the good complying patients.

3.7 | Health-related quality of life

3.7.1 | Cross-sectional study

The total score of child-reported health-related quality of life was significantly lower in TX than in CON (75.0 ± 14.9 vs 85.2 ± 7.6; $P = .017$). In TX, a high inter-individual variability concerning health-related quality of life was observed. However, it was lowest in patients with no regular physical activity per week. Health-related quality of life was comparable for all activity subgroups of CON (Figure 2F).
3.7.2 | Exercise intervention

TX_{Wii} showed no significant improvement in overall health-related quality of life score after 6 weeks of active video gaming (Figure 3F). In contrast to the low-compliant subgroup, the complying patients showed an average increase of 7% in health-related quality of life after intervention.

4 | DISCUSSION

This is the first controlled study that investigated physical performance and the impact of active video gaming for fitness improvement in TX. The key results are that all performance tests, except the handgrip strength test, were substantially impaired in this patient population compared to CON. Home-based exergaming over 6 weeks did not improve these items. Hence, active video gaming cannot easily be used for an improvement of cardiorespiratory fitness, motor coordination, and health-related quality of life in pediatric renal transplanted patients. Only 5 out of 13 young patients of the TX_{Wii} subgroup regularly performed the required exercises with the Wii fit console. The recorded heart rates and the reported ratings of perceived exertion during exercising revealed a low effort, not sufficient to induce a significant increase in VO_{peak} after 6 weeks of exergaming. However, daily physical activity was significantly increased in TX_{Wii} after the intervention, but it was still reduced compared to the CON.

The transplanted young patients and the CON of the present investigation did not reach the above mentioned recommendations for children and adolescents regarding daily physical activity. On average, the transplanted patients wore the SenseWear® armband for 15.3 hours while being awake and did approximately 7007 steps per day. They were less active than the controls with 10 305 steps on average within 15 hours. They were also less active compared with pediatric kidney-transplanted cohorts of other studies. After 6 weeks of active video gaming, daily physical activity was significantly increased by 121 steps per hour (approximately 2720 steps per day). This increase was not only observed in those young patients who adhered to the prescribed exercises. It can be assumed that the participation in the present study and/or wearing
the SenseWear® armband per se motivated the pediatric renal transplanted patients to moderately increase their daily physical activity. A similar observation was made in another study with TX, where the use of pedometers over a 12-week period in conjunction with weekly targeted step counts and with the information about the benefits of physical activity also resulted in a significant increase of steps per day. While fatigue and illness have been identified as the main causes for reduced physical activity in end-stage renal disease before transplantation, the fear to injure the transplanted kidney during physical activity is regarded as the dominant reason for limited activity, especially for participation in sports after renal transplantation. However, in the study of Wolf et al, only three out of 101 patients reported a kidney injury due to physical activities (football, baseball, and falling out of a tree), but none of these patients had to be hospitalized. 

Because the majority of the pediatric kidney-transplanted patients of the present study lived far away from the renal transplantation outpatient clinic, a home-based exergaming intervention was chosen. It was assumed that providing the children and adolescents with the exergaming technology and a heart rate monitor and, additionally, explaining to them and their parents the importance of regular physical activity as well as regularly contacting them during the 6-week intervention might mean enough motivation to perform the suggested exercises. Positive effects and high compliance have been reported in overweight and obese children for a 24-week home-based exergaming intervention as well as for 10 weekly facilitated exergaming sessions. However, in the TX of the present study, compliance was low, probably at least partly due to disordered motor competence.

To our knowledge, the present study is the first that investigated motor coordination in TX. Motor coordination was found to be on the lowest measurable level according to Kiphard and Schilling, two levels below the normal values of the CON. The substantial limitations in motor competence could have caused an enormous mental effort to correctly perform the required exercises and might also provide an explanation for the low heart rate (65% of peak heart rate) during the aerobic exercises of the active video game sessions. Differences in the execution of exercises in active video games were observed between healthy weight and obese children causing less energy expenditure and therefore smaller cardio-metabolic benefits in obese children. It is very likely that the TX of the present study were discouraged by the high coordinative effort, and this high mental and coordinative effort might also have intensified the concern to injure the kidney by physical activity. In accordance, a high dropout rate has previously been reported for programs intending to increase physical activity of children with chronic kidney disease. However, Wii game interventions can have positive effects on motor coordination in children with developmental coordination disorder and with poor motor performance. In contrast to the present study, these investigations were supervised and took place in small groups during school time on school premises. As motor coordination is one of the basic motoric skills and mainly developed in early childhood, it can be assumed that chronic kidney disease at a young age has a negative effect on motor competence. The pediatric patients of the present study were 4.5 years after renal transplantation on the
average (range, 8 months to 15 years), and they had mostly been inactive during all the time. But, in accordance with the observation of Wolf et al.,\textsuperscript{31} no significant correlations between the motor coordination levels and the age at primary diagnosis, the age at renal transplantation, or the elapsed time after renal transplantation were found.

In contrast to adult renal transplant recipients, who significantly increased their performance in a 6-minute walk test after exergaming three times per week for 30 minutes for 8 weeks,\textsuperscript{13} cardiorespiratory fitness assessed by VO\textsubscript{2peak} measurement and determination of VO\textsubscript{2} at the ventilatory thresholds did not significantly increase in the renal transplanted children and adolescents of the present study, who regularly performed the prescribed exercises. In the low-compliant young patients, there was even a slight decrease in VO\textsubscript{2peak}, probably indicating an adverse development in cardiorespiratory fitness, if inactivity continues in these young patients. There are only few studies with measurement of VO\textsubscript{2peak} in TX. Consistently lower VO\textsubscript{2peak} values were found in renal transplanted children and adolescents than in healthy peers\textsuperscript{2,4,5,7} or in children with a congenital solitary kidney\textsuperscript{24} similar to the results of the present study. However, VO\textsubscript{2peak} of TX can be increased to the values of healthy children with a sedentary lifestyle by physical exercise of 3-5 hours per week as shown by Lubrano et al.\textsuperscript{5} The results of Thorsteinsdottir et al.\textsuperscript{10} point into the same direction. In children, who regularly received physiotherapy as early as 1-2 weeks after transplantation with individualized increments during the first 3 months post-transplant and regular encouragement for physical exercises, significantly higher VO\textsubscript{2peak} was observed 1-year post-transplant than in TX without such treatment.

Low physical activity and impaired cardiorespiratory fitness worsen the impaired health-related quality of life in children with chronic disease. Consistent with other studies,\textsuperscript{3,35,36} health-related quality of life was significantly reduced in pediatric renal transplanted patients compared with CON in the present investigation. The association between health-related quality of life and physical activity levels is well known.\textsuperscript{37} Also, Thorsteinsdottir et al.\textsuperscript{10} who observed improved cardiorespiratory fitness in physically active renal transplanted children and adolescents, reported improved health-related quality of life in these patients. In the present study, higher PedsQL\textsuperscript{™} scores could be observed for the moderately active transplanted patients compared with the regularly inactive young patients. However, in contrast to Hamiwicka et al.,\textsuperscript{3} no significant correlation between the number of steps and the health-related quality of life was found for both, the transplanted and healthy participants.

Maximal handgrip strength was the only parameter which was not significantly reduced in TX compared to healthy peers in the present study. Maximal isometric handgrip strength is often regarded as a valuable measure for the musculoskeletal development of children and adolescents and has been used to assess the health status and muscle strength in different populations, also in TX.\textsuperscript{38,39} With regard to age-specific references for healthy children and adolescents,\textsuperscript{40} the maximal handgrip strength of the renal transplanted patients and of the healthy controls of the present study were within the normal ranges. The data suggest that the maximal isometric handgrip strength test is not a valuable measure for the health status and muscle strength in renal transplanted children and adolescents.

The strengths of our study are the prospective and controlled study design and the multimodal examination of physical performance and activity. Limitations are the relatively low number of investigated patients and the inter-individual variability with regard to their medication with potential (small) impact on cardiorespiratory performance capacity, for example, beta blockers. But these are inherent problems in this rare and vulnerable patient population.

The present study revealed a considerably impaired motor competence in TX as a main new finding and provided further evidence for a significantly reduced cardiorespiratory fitness, daily physical activity, and health-related quality of life in these patients compared with healthy peers. In contrast to other active video game investigations, reporting improvements in motor competence, fitness and quality of life of children, and adolescents,\textsuperscript{14,16-19} six weeks of home-based Wii gaming turned out to be not appropriate to improve these items in TX. However, the active video game intervention provided a sufficient stimulus for an increase in daily physical activity. Considering the low compliance in the present study, high dropout rates in previous studies\textsuperscript{32} and the increase in cardiorespiratory fitness in pediatric renal transplanted patients individually treated with physiotherapy,\textsuperscript{10} and individualized exercise programs starting with short latency after transplantation or even in preparation for transplantation should be developed and permanently integrated in the patients everyday life. Additionally, physicians and especially parents should be activated to promote and support an active and healthy lifestyle of these young patients.

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CONFLICT OF INTEREST

The authors have no conflict of interest to report.

AUTHOR CONTRIBUTIONS

Sandra Weigmann-Faßbender, Kathrin Pfeil, Birgit Friedmann-Bette, and Burkhard Tönshoff: Initiated and planned the study; Sandra Weigmann-Faßbender, Kathrin Pfeil, and Theresa Betz: Conducted the investigations and collected the relevant data. Klaus Weiß: Provided the SenseWear® devices as well as the SenseWear® Professional software, prepared them for data collection, and supported Sandra Weigmann-Faßbender with the SenseWear® data analysis; Sandra
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