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The impact of computer use on myopia development in childhood: The Generation R study

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ABSTRACT

Environmental factors are important in the development of myopia. There is still limited evidence as to whether computer use is a risk factor. The aim of this study is to investigate the association between computer use and myopia in the context of other near work activities.

Within the birth cohort study Generation R, we studied 5074 children born in Rotterdam between 2002 and 2006. Refractive error and axial length was measured at ages 6 and 9. Information on computer use and outdoor exposure was obtained at age 3, 6 and 9 years using a questionnaire, and reading time and reading distance were assessed at age 9 years. Myopia prevalence (spherical equivalent ≤–0.5 dioptre) was 11.5% at 9 years. Mean computer use was associated with myopia at age 9 (OR = 1.005, 95% CI = 1.001–1.009), as was reading time and reading distance (OR = 1.031; 95% CI = 1.007–1.055 (5–10 h/wk); OR = 1.113; 95% CI = 1.073–1.155 (> 10 h/wk) and OR = 1.072; 95% CI = 1.048–1.097 respectively). The combined effect of near work (computer use, reading time and reading distance) showed an increased odds ratio for myopia at age 9 (OR = 1.072; 95% CI = 1.047–1.098), while outdoor exposure showed a decreased odds ratio (OR = 0.996; 95% CI = 0.994–0.999) and the interaction term was significant (P = 0.036). From our results, we can conclude that within our sample of children, increased computer use is associated with myopia development. The effect of combined near work was decreased by outdoor exposure. The risks of digital devices on myopia and the protection by outdoor exposure should become widely known. Public campaigns are warranted.

1. Introduction

Myopia, or near-sightedness, is a refractive error of the eye that can be corrected by glasses or contact lenses. It is primarily caused by a combination of crystalline lens thinning and excessive elongation of the eyeball resulting in thinning of all retinal layers (Wong et al., 2010; Li et al., 2016). In particular, high degrees of myopia (−6 diopters or worse), is associated with retinal complications causing irreversible visual impairment later in life (Verhoeven et al., 2015). The prevalence of myopia has increased rapidly in the last decades. Over 80% of the university students in highly urbanized areas in East Asia are currently myopic; Europe is following with 50% of the young adults developing myopia (Foster and Jiang, 2014; Lin et al., 2004; Williams et al., 2015).

Known risk factors for myopia are lifestyle factors including lack of outdoor exposure, near work duration and near working distance (Huang et al., 2015; Ip et al., 2008; Rose et al., 2008a). Concerns or awareness of digital devices on children's health is increasing (Holloway et al., 2013; Ebbeck et al., 2016; American Academy of P. Media and young minds, 2016; Xiong et al., 2017a). The exact contribution of digital screens to the total time spent on near work by children is unknown, but a recent study showed that children aged 0 to 8 years spent on average more than 1 h per day on a computer, tablet or smartphone (Lauricella et al., 2015). However, there is still limited evidence of whether computer use is a risk factor for myopia (Smaldone et al., 2015). Cross-sectional studies showed conflicting results and evidence from longitudinal studies is scarce (Smaldone et al., 2015; Saw

Abbreviations: SER, Spherical equivalent; AL, Axial length; H/wk, Hours per week; Sd, Standard deviation; Mm, Millimeter

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et al., 2002a). We analyzed data from the prospective birth cohort the Generation R study, where computer use was measured at the age of 3, 6 and 9 years. Our first aim was to determine the association between computer use and myopia and axial elongation. Our second aim was to relate the effect of computer use to other near work activities associated with myopia and axial elongation. The third aim was to investigate whether the effect of near work can be modified by outdoor exposure.

2. Methods

2.1. Study population

Generation R is a population-based prospective birth cohort of 9778 pregnant women and their children who were born between April 2002 and January 2006 in Rotterdam, The Netherlands. Details of the methodology of this study has been described elsewhere (Kooijman et al., 2016; Kruithof et al., 2014). Of the initial cohort, 5431 (55.5%) children visited the research centre at both the age of 6 and 9 years. Children with computer use measurements of at least one time point (age 3, 6 or 9) were included in the study ($N = 5076$). Only 2 out of 5076 children did not have any eye measurements and were therefore excluded, leaving 5074 children available for analyses (Fig. S1). The study protocol was approved by the Medical Ethical Committee of the Erasmus Medical Centre, Rotterdam (MEC 217.595/2002/20), and written informed consent was obtained from all parents.

2.2. Eye measurements

At both 6 and 9 years, visual acuity was measured with LEA charts at a 3-m distance by means of the Early Treatment Diabetic Retinopathy Study method (Camparini et al., 2001). In children with visual acuity of > 0.1 logarithm of the minimum angle of resolution (LogMAR) (visual acuity < 0.8 Decimal) in at least 1 eye, or in children with an ophthalmologic history automated cycloplegic refractive error was performed using a Topcon KR8900 instrument (Topcon, Japan). Those with visual acuity of ≤0.1 LogMAR, no glasses, and no ophthalmic history were classified as non-myopic (Leone et al., 2010; O'Donoghue et al., 2012). Two drops (three in case of dark irises) of cyclopentolate (1%) with 5 min interval were dispensed, and refractive error measurements were performed at least 30 min thereafter when pupil diameter was ≥6 mm. Automated cycloplegic refractive error measurement regardless of visual acuity was introduced for all children during the research phase at 9 years. Myopia was defined as spherical equivalent (SER) ≤–0.5 dioptre in at least one eye. Ocular biometry was measured by Zeiss IOL-master 500 (Carl Zeiss MEDITEC IOL-master, Jena, Germany). For axial length (AL), five measurements per eye were averaged to mean AL. Axial elongation was calculated in millimetres per year by taking the difference between AL at age 6 and 9 divided by the time in years between measurements. Mean axial elongation of two eyes was used in the analyses.

2.3. Computer use, outdoor exposure, reading time and reading distance

Desktop computer use and outdoor exposure were measured at age 3, 6 and 9 years using a questionnaire filled out by the parent/legal guardian. The question "how much time does your child use the computer in the morning/afternoon/evening" was asked for weekdays and weekend days separately. Total hours computer use per week was computed as the sum of 5 times weekdays and 2 times weekend days. The average amount of computer use was estimated by the sum of computer use at age 3, 6 and 9 divided by 3. For outdoor exposure, the questions "how many days per week does your child play outside" and "how long does your child approximately play outside per day" were asked. Mean daily outdoor exposure was calculated by multiplying the number of days by time in minutes divided by seven. Walking or cycling to and from school was asked at age 6 and 9 years and was processed similarly. Outdoor exposure was calculated as the sum of playing outside and walking or cycling to and from school. Groups of low (< 7.0 h/wk), medium (7.0–14.0 h/wk) and high (> 14 h/wk) outdoor exposure were created. Children with > 40 h computer use per week were set to 40 h per week ($N = 15$). Time spent reading was asked per week (< 5 h/wk, 5–10 h/wk. or > 10 h/wk), and reading distance was asked for < 30 cm or ≥30 cm at age 9.

2.4. Potential confounders

Ethnic background was determined by questionnaire and children were classified into European or non-European. Other potential confounders were sex and age (Wu et al., 2015; You et al., 2012; Zhou et al., 2016).

2.5. Statistical analyses

Myopia (yes/no) was considered the dichotomous outcome variable ($N = 5021$ at 6 years, $N = 4706$ at 9 years); Axial elongation (mm/year) was used as the continuous outcome ($N = 4511$). Axial elongation was positively skewed, therefore log transformation was performed on this variable. Missing information on determinants and covariates varied between 0% and 35% (Table 1). Multiple imputation procedures to replace missing covariates for the most likely values were performed using Multivariate Imputations by Chained Equations (MICE) (van Buuren and Groothuis-Oudshoorn, 2011). First, parallel logistic and linear regression models were performed with computer use as determinant, and myopia at 6 and 9 years, and axial elongation as outcomes, and the average amount of computer use over time with myopia at 9 years and axial elongation as the outcomes. Second, conditional analyses taking into account the correlation between computer use measurements over time were applied to identify the most important time period (Keijzer-Veen et al., 2005). Z-scores of computer use were created and regressed on earlier computer use measures. We calculated two conditional computer use variables; computer use at age 6 years condition on computer use at age 3 years (6|3) and computer use at age 9 years condition on computer use at age 6 and 9 years (9|3 and 6), by saving the standardized residuals of the regression analyses. The

Table 1
General characteristics.

Generation R cohort ($N = 5074$)	Age 3	Age 6	Age 9
Age (± SD; years)	3.05	6.10 (0.44)	9.78 (0.34)
Missing (%)	26.8	0	0
Sex (% ♀)	50.1	50.1	50.1
Missing (%)	0	0	0
Ethnicity (% EUR)	70.2	70.2	70.2
Missing (%)	0.6	0.6	0.6
Myopia (%)	–	2.2	11.5
Missing (%)	–	1.0	3.5
Axial length (± SD; mm)	–	22.34 (0.74)	23.09 (0.84)
Missing (%)	–	5.3	6.2
Axial elongation (± SD; mm/yr)	–	–	0.21 (0.08)
Missing (%)	–	–	11.1
Computer use (± SD; hr/week)	0.49 (1.79)	2.19 (3.27)	5.17 (5.51)
Missing (%)	29.0	13.0	18.2
Outdoor exposure (± SD; hr/week)	11.2 (5.85)	11.7 (7.90)	7.6 (5.23)
Low < 7.0 h/wk (%)	36.9	30.1	53.7
Medium 7.0–14.0 h/wk (%)	37.6	38.5	32.0
High > 14.0 h/wk (%)	25.5	31.4	14.3
Missing (%)	29.6	24.9	15.3
Reading time	–	–	
< 5 h/wk (%)			62.2
5–10 h/wk (%)			30.0
> 10 h/wk (%)			7.8
Missing (%)			30.8
Reading distance (% < 30 cm)	–	–	48.6
Missing (%)			35.0

conditional z-score is a measure of computer use change between two time points, and can be interpreted as computer use above or below the expected given earlier computer use (Wills et al., 2010). Third, the strength of the associations of different types of near work activities on myopia at age 9 years and axial elongation was determined. Computer use and reading time at age 9 years were compared by creating similar cut-of values (< 5 h/wk, 5–10 h/wk and > 10 h/wk). Univariate regression analyses were performed for computer use, reading time and reading distance on myopia at age 9 years and axial elongation. Fourth, a weighted risk score was created by combining the effects of computer use, reading time, and reading distance. All three were standardized to avoid variables with larger ranges having a greater importance on the outcome. A multivariate, logistic regression on mean computer use, reading time and reading distance was built. The risk score was computed for each individual using the natural logarithm of the odds ratios of the final multivariate regression model multiplied by the standardized values of the near work variables. Logistic and linear regression analyses were performed to test for interactions with the near work risk score and outdoor exposure. *P*-values < 0.05 were considered to be significant for interaction analyses. All analyses were performed with the full dataset (*N* = 5074) minimizing selection bias. Sensitivity analyses were performed with complete computer use measurements (*N* = 2745 in total, *N* = 2716 for myopia at 6, *N* = 2624 for myopia at 9, and *N* = 2507 for axial elongation).

3. Results

Half (50.1%) of the children were girls, and 70.2% were from European ethnicity. The mean age (sd) at eye measurements was 6.10 (0.44) and 9.78 (0.34) years (Table 1). Myopia prevalence was 2.2% at 6 years and 11.5% at 9 years. Axial length (sd) was 22.34 (0.74) mm at 6 years and 23.09 (0.84) mm at 9 years. Mean weekly computer use (sd) was 0.49 (1.79) hr/wk at the age of 3 years (*N* = 3604), 2.19 (3.27) hr/wk at the age of 6 years (*N* = 4413), and 5.17 (5.51) hr/wk at 9 years of age (*N* = 4150; Table 1). Children from non-European ethnicity spent more time on a computer at age 3, 6 and 9, less time outdoors at age 3, 6 and 9, and less time reading at age 9 years.

Logistic regression analyses showed significant associations between computer use at 3 years and myopia at 6 and 9 years, (OR = 1.005, 95% CI = 1.002–1.010; OR = 1.009, 95% CI = 1.002–1.017), and borderline significant associations with computer use at 9 years and myopia at 9 years and axial elongation (OR = 1.002, 95% CI = 1.000–1.009; β = 0.002, 95% CI = $4.51e^{-4}$–0.005). The cumulative time of computer use in childhood (mean computer use) was significantly associated with myopia at 9 years (OR = 1.005, 95% CI = 1.001–1.009), but not with axial elongation (Table 2). Sensitivity analyses on the complete dataset (*N* = 2745) showed similar results, however, computer use at 3 years became insignificant with respect to myopia at 6 and 9 years, and computer use at 9 years and mean total computer use were significant with respect to myopia at 9 years (OR = 1.003, 95% CI = 1.001–1.005; OR = 1.007, 95% CI = 1.002–1.013 respectively) and axial elongation (β = 0.004, 95% CI = 0.001–0.007; β = 0.008, 95% CI = 0.001–0.016 respectively) (Table S1). Effects were similar for Europeans and non-Europeans (data not shown); outdoor exposure did not correlate with computer use (Fig. S2).

We performed conditional analyses to identify whether a particular age period was most important by adjusting for previous computer use. The strongest association was at 3 years in the full dataset (OR = 1.018; 95% CI = 1.004–1.033 for myopia; β = 0.015, 95% CI = 0.007–0.030 for axial elongation). However, conditional analyses on the complete dataset (N = 2745) showed the strongest association for computer use at 9 years (OR = 1.012; 95% CI = 1.000–1.024 for myopia; β = 0.018, 95% CI = 0.002–0.034 for axial elongation) (Tables S2 and S3). These discrepancies prompted us to perform all further analyses with mean computer use.

Table 2
Logistic regression analyses of computer use on myopia at 6 and 9 years and axial elongation.

Myopia at 6 years; *N* = 5021	Odds ratio	95% CI	
Computer use at 3 years	1.005	1.002	1.009
Computer use at 6 years	1.000	0.999	1.001
Myopia at 9 years; *N* = 4706	**Odds ratio**	**95% CI**	
Computer use at 3 years	1.009	1.003	1.017
Computer use at 6 years	1.001	0.998	1.004
Computer use at 9 years	1.002	1.000	1.003
Mean computer use	1.005	1.001	1.009
Axial elongation; *N* = 4511	**Estimate**	**95% CI**	
Computer use at 3 years	0.008	$-9.50e^{-5}$	0.015
Computer use at 6 years	−0.002	−0.006	0.002
Computer use at 9 years	0.002	$-4.51e^{-4}$	0.005
Mean computer use	0.004	−0.002	0.009

Adjusted for age, sex, ethnicity; *N* = 5021 for myopia at age 6; *N* = 4706 for myopia at age 9; *N* = 4511 for axial elongation. Axial elongation was log transformed.

Reading time at age 9 was associated with myopia at 9 years as well as axial elongation (OR = 1.034, 95% CI = 1.009–1.059 and OR = 1.112, 95% CI = 1.069–1.158 for myopia; β = 0.066, 95% CI = 0.033–0.099 and β = 0.147, 95% CI = 0.093–0.201 for axial elongation), while computer use at 9 years was not significantly associated when using similar cut-off values for both variables (Table 3). Reading distance was associated with myopia at age 9, but not with axial elongation (OR = 1.069, 95% CI = 1.044–1.095 for myopia; β = 0.022, 95% CI = −0.011–0.055 for axial elongation; Table 3).

Near work risk scores were calculated by weighting mean computer use, reading time, and reading distance (Table S4). The near work risk

Table 3
Logistic and linear univariate regression analyses of computer use, reading time, and reading distance on myopia at 9 years and axial elongation.

Myopia at 9 years; *N* = 4706	Odds ratio	95% CI	
Computer use at 9 years			
< 5 h/wk	Ref		
5–10 h/wk	1.004	0.981	1.027
> 10 h/wk	1.004	0.974	1.034
Reading time at 9 years			
< 5 h/wk	Ref		
5–10 h/wk	1.034	1.009	1.059
> 10 h/wk	1.112	1.069	1.158
Reading distance			
> 30 cm	1.069	1.044	1.095
Axial elongation; *N* = 4511	**Estimate**	**95% CI**	
Computer use at 9 years			
< 5 h/wk	Ref		
5–10 h/wk	0.006	−0.025	0.036
			0.063
> 10 h/wk	0.019	−0.026	0.063
Reading time at 9 years			
< 5 h/wk	Ref		
5–10 h/wk	0.066	0.033	0.099
> 10 h/wk	0.147	0.093	0.201
Reading distance			
> 30 cm	0.022	−0.011	0.055

Adjusted for age, sex and ethnicity; *N* = 4706 for myopia at age 9; *N* = 4511 for axial elongation. Axial elongation was log transformed.

Table 4
Linear and logistic regression analyses of the near work risk score and mean outdoor exposure including interaction on myopia at 9 years and on axial elongation.

Myopia at 9 years; $N = 4706$	Odds ratio	95% CI	
Near work risk score	1.071	1.045	1.099
Mean outdoor exposure	0.996	0.994	0.998
Near work risk score * mean outdoor exposure	0.998	0.995	1.000

Axial elongation; $N = 4511$	Estimate	95% CI	
Near work risk score	0.054	0.020	0.088
Mean outdoor exposure	−0.004	−0.008	−0.001
Near work risk score * mean outdoor exposure	−0.002	−0.005	0.002

Adjusted for age, sex and ethnicity; $N = 4706$ for myopia at age 9; $N = 4511$ for axial elongation. Axial elongation was log transformed.

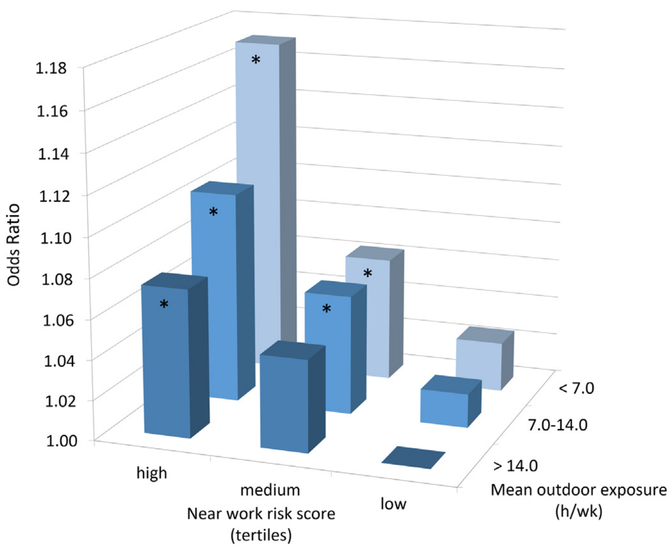

Fig. 1. Odds ratios for near work risk tertiles and mean outdoor exposure on myopia at age 9 years, adjusted for age, sex and ethnicity. Near work risk tertiles represent the combined risk of computer use, reading and reading distance. Outdoor exposure was divided into < 7, 7–14 and > 14 hour per week. The group with low near risk and > 14 hour per week of outdoor exposure was the reference group.

score and mean outdoor exposure were associated with myopia at age 9 and axial elongation, as was the interaction term for myopia at 9 years (*P* for interaction = 0.030). The effect of near work activities decreased within higher levels of outdoor exposure (Table 4; Fig. 1).

4. Discussion

In our study cohort consisting of 5074 children from the Generation R study, we found that computer use in young children was moderately associated with myopia. Reading time had a stronger association, suggesting that prolonged hours of reading books may result in a higher risk of myopia than desktop computer screens. Notably, the effect of combined near work activities could be diminished by outdoor exposure.

The results between myopia prevalence and axial elongation as outcomes were largely similar. Previous literature showed that one millimetre change in AL represents on average a 3 diopter change in SER (Cruickshank and Logan, 2018; Lam et al., 2001). However the relationship attenuated to 1 mm increase equals −1.75 diopter change in high myopes, suggesting that the mathematical relationship between AL en SER is different (Cruickshank and Logan, 2018). Hence, other compensatory refractive structures, such as the crystalline lens thickness, may have a dampening effect explaining the small differences in results with axial elongation and myopia as outcomes (Li et al., 2016). Our Zeiss IOL-master 500 did not measure lens thickness, and we recommend future research to take crystalline lens thickness into account.

Whether computer use is a risk factor for myopia has been questioned for a long time (Mutti and Zadnik, 1996). Although this topic has been studied extensively, most studies were cross-sectional and results were inconclusive (Ip et al., 2008; Mutti et al., 2002; Rose et al., 2008b; Saw et al., 2002b; Qian et al., 2016). In our longitudinal study, computer use already at age 3 years was associated with myopia occurring at school age. Few other longitudinal studies have been performed on this topic; two of them reported an association between computer use and myopia progression (Fernandez-Montero et al., 2015; Lee et al., 2015). Both studies were performed in young adults after the development of myopia, jeopardizing the conclusion of a causal relation.

Given the evidence from a recent meta-analysis on observational studies, total near work was recognized as a risk factor for myopia, despite the lack of randomized controlled trials (Huang et al., 2015). This study underlines the consequences of near work activities in childhood. In our study, we confirmed that reading time and reading distance were associated with myopia and axial elongation (Ip et al., 2008; Lee et al., 2015; Guo et al., 2016; Gwiazda et al., 2004). In relation to reading habits, the effect of computer use appeared somewhat less strong, which may relate to the fact that reading books involves a closer reading distance than using a desktop computer.

A causal association between outdoor exposure in childhood and myopia incidence and progression has been well established by multiple randomized controlled trials (Xiong et al., 2017b; Wu et al., 2018; Wu et al., 2013). The results of our study suggest that the hours of outdoor exposure needed to prevent children from myopia depends on the intensity of near work activities. Results were in line with findings from Rose et al. (2008), who reported that the effect of near work may be modified by outdoor exposure (Rose et al., 2008a; French et al., 2013). An important question is whether outdoor exposure during daylight has an extra protective effect or whether simply not being indoors and involved in near work is the key factor. In our cohort of children, outdoor exposure was not correlated with computer use at all ages, suggesting that not being outdoors does not necessarily involve near work, hinting towards an extra protective effect of outdoor exposure. A longitudinal study observed that a minimal of 12 h/wk outdoor exposure in childhood was needed to remain non-myopic (Jones et al., 2007). The results of our study suggested that > 7 h/wk is needed to compensate low intensity near work, and > 14 h/wk for protection against medium or high intensity near work.

Even though the effect sizes identified in our study are relatively small, our results may have a large impact on a population scale. A recently published paper on sedentary behavior among the US population showed that computer use > 1 h/day has increased from 43% in 2001–2002 to 56% in 2015–2016 in young children (Yang et al., 2019). The use of handheld digital devices was not taken into account, and it is likely that they have an even greater effect on myopia because of their shorter reading distance than computers.

A strength of this study is the longitudinal design; computer use was measured at three different time points and eye measurements were performed at two different time points. We were therefore able to identify the association with early onset myopia and myopia progression by using axial elongation. This study also benefitted from a large sample size and the young age of the children. Nevertheless, some limitations should be borne in mind. Around 45% of the study cohort had missing information on computer use at 1 (31.6%) or 2 (14.3%) time points. Children with missing information did not differ in sex, outdoor exposure, reading time, or reading distance, but were more often non-European (50.1% versus 18.5%; $P < 0.001$). Therefore, we performed multiple imputation procedures to include these children in the main analyses. Sensitivity analyses on the complete dataset showed similar results indicating no large bias. Unfortunately, potential risk factors were assessed by questionnaires filled out by parents which could have resulted in socially desired answers (Rah et al., 2002). This may explain our inconsistent findings for computer use at the different time points. Automated measurements are currently under development, and may provide more objective digital exposures.

5. Conclusion

Our results showed that computer use, especially at a very young age, is moderately associated with myopia development in childhood. Reading time had a stronger association with myopia, possibly because of a shorter near work distance. The effect of combined near work activities could be lowered by outdoor exposure. It is likely that the increased use of digital devices may have an impact on myopia development in the coming years. Therefore, regulating its use, and maximizing outdoor exposure in young children should be the main focus for myopia prevention.

Authors' contributions

CE designed the study, carried out the analyses, drafted the initial manuscript, and reviewed and revised the manuscript. CK conceptualized and designed the study, was responsible for the finances of the study, coordinated and supervised data collection, and reviewed and revised the manuscript. JT collected data, contributed on the analyses and reviewed and revised the manuscript. JP designed the data collection instruments, and reviewed and revised the manuscript. HR and JY contributed on the analyses, and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Appendix A. Supplementary data

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