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Eggs versus chewable vitamins: Which intervention can increase nutrition and test scores in rural China?

Max KLEIMAN-WEINER [a], Renfu LUO [b,*], Linxiu ZHANG [b], Yaojiang SHI [c], Alexis MEDINA [d], Scott ROZELLE [d]

[a] *Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA*
[b] *Center for Chinese Agricultural Policy, Institute of Geographcial Sciences and Natural Resources Research, Chinese Academy of Sciences, No. Jia 11, Datun Road, Chaoyang District, Beijing 100101, China*
[c] *Northwest Socioeconomic Development Research Center (NSDRC), Suite 8502, School of Economics and Management, South Campus of Northwest University, Xi'an 710127, China*
[d] *Freeman Spogli Institute for International Studies, Stanford University, 616 Serra Street, Stanford, CA 94305, USA*

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ABSTRACT

Despite growing wealth and a strengthening commitment from the government to provide quality education, a significant share of students across rural China still have inadequate access to micronutrient-rich regular diets. Such poor diets can lead to nutritional problems, such as iron-deficiency anemia, that can adversely affect attention and learning in school. Large scale policies in Northwestern China have attempted to tackle these nutritional problems using eggs. The overall goal of this paper is to assess the impact of the government's egg distribution program by comparing the effect on anemia rates of an intervention that gives students an egg per day versus an intervention that gives students a chewable vitamin per day. We will also assess whether either intervention leads to improved educational performance among students in poor areas of rural China. To meet this goal, we report on the results of a randomized controlled trial (RCT) involving over 2600 fourth grade students from 70 randomly-chosen elementary schools in 5 of the poorest counties in Gansu Province in China's poor Northwest region. The design called for random assignment of schools to one of two intervention groups, or a control group with no intervention. One intervention provided a daily chewable vitamin, including 5 mg of iron. The other mimicked the government policy by providing a daily egg. According to the findings of the paper, in the schools that received the chewable vitamins, hemoglobin (Hb) levels rose by more than 2 g/L (over 0.2 standard deviations). The standardized math test scores of students in these schools also improved significantly. In schools that received eggs, there was no significant effect on Hb levels or math test scores. Overall, these results should encourage China's Ministry of Education (MOE) to look beyond eggs when tackling nutritional problems related to anemia in an education setting.

1. Introduction

Despite increasing investment in rural China and rising incomes, the academic achievement of children in rural areas has persistently lagged behind that of children in cities. This performance gap can be readily observed in high school graduation rates, where rural students are 50% less likely to graduate from an academic or vocational high school than are students living in urban areas (Ministry of Education, 2006; Wang et al., 2011). In college and tertiary education the statistics are even more striking: 50%

* Corresponding author at: Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, No. 11 Jia Datun Road, Anwai, Beijing, China 100101. Tel.: +86 10 64888990.
E-mail address: luorf.ccap@igsnrr.ac.cn (R. Luo).

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of students in China's large municipalities will receive some tertiary education compared with only 5% of those in poor rural areas (Liu et al., 2011).

The high rates of return to higher education in China and the fact that access to higher education facilitates access to formal jobs with benefits and other rights mean that the poor performance of rural students is reinforcing inequality trends (Li, Liu, Ma, & Zhang, 2005; Wang, Fleisher, Li, & Shi, 2007). Moreover, it has been shown that there are intra-household externalities of education (Gao, 2009). When poor rural students go to college there are benefits for family members and neighbors who remain in the home communities (L. Zhang, Luo, Liu, & Rozelle, 2006).

Given such benefits, why are rural students forgoing secondary and tertiary education? Three possible explanations readily emerge to explain this reduced enrollment: first, insufficient knowledge about the gains provided by education; second, the high cost of tuition at the secondary and tertiary levels; and third and finally, the inability to test into high school (either at all, or into one that can provide a quality education).

In assessing which of these explanations might have the most explanatory power, there are reasons to doubt the first two (rural families do not appreciate the importance of education and tuition is too high). After more than 20 years of reform and experience in the off farm labor market, the returns to household income and increased economic mobility provided by education is certainly known and appreciated by Chinese families. Indeed while the exact rate of return to educational attainment is not known, most families will tell you it is positive and high (Loyalka, Song, & Yi, 2012). Moreover, while rural incomes have not increased quite as fast as urban incomes, rural incomes have risen steadily over the past 30 years (and especially in the past 10 years) and most families have more disposable income – and access to cash subsidies and government support programs – than ever before (Huang, Wang, Zhi, Huang, & Rozelle, 2011; Park, Cai, & Du, 2007).

In contrast, there is abundant evidence of fundamental differences in educational performance between rural and urban students when examining metrics on performance in school and on standardized tests (Webster & Fisher, 2000; Young, 1998). The differences in scores on mathematics achievement tests indicate that students from rural areas are significantly behind students from urban areas in learning mathematics (Mohandas, 2000). Indeed in one study, the test scores of urban students were greater than one standard deviation above those of rural students when taking a standardized TIMSS test (Lai et al., 2011). As a whole, these results suggest that by the time rural students reach junior high school, they have already fallen behind academically to the point where they often cannot adequately compete with students from urban backgrounds and, in a competitive school system like that in China, are thus ineligible for many academic options.

Therefore, an even more fundamental question is why rural students – especially those from poor rural areas – are scoring so much lower than urban students on standardized tests and doing so poorly in school. There are many possible reasons. School facilities and teachers are systematically better in urban areas (World Bank, 2001). There is greater investment per capita in urban students relative to rural students (MOE and NBS (Ministry of Education and National Bureau of Statistics), 2004; Tsang & Ding, 2005). Parents of urban students also have higher education and more time and opportunities to help their children in their studies (Huang & Du, 2007).

There is one additional factor that may be affecting the educational performance (and scores) of students from poor rural areas: micronutrient deficiencies, and, in particular, iron deficiency anemia. Iron deficiency anemia (or simply anemia in the rest of the paper) is a debilitating health condition that affects hundreds of millions of people worldwide, mostly in developing countries, as the poor are often restricted to starch based diets with little vegetables or meat (Yip, 2001). A large body of research links anemia (as well as iron deficiency) with cognitive impairment and altered brain function; indeed iron deficiency and anemia have been shown to be negatively correlated with educational outcomes, such as grades, attendance and attainment (Bobonis, Miguel, & Puri-Sharma, 2006; Halterman, Kaczorowski, Aligne, Auinger, & Szilagyi, 2001; Stoltzfus, 2001; Stoltzfus et al., 2001).

Our recent work in three separate studies has established this relationship in rural China as well (Luo et al., 2012; Miller et al., 2012; Wong, Shi, Luo, Zhang, & Rozelle, 2012). According to a 2008–09 study in Shaanxi Province, children with anemia lagged behind their healthier peers academically, physically and psychologically (Luo et al., 2012). The study showed that iron supplementation was not only able to improve student nutrition (through increased hemoglobin levels) and health (through reduced anemia), it also improved the test scores of anemic students. Another study in the same province – but in a different set of counties – generated almost identical results in 2009–10; iron supplementation led to falling rates of anemia and higher test scores (Wong et al., 2012). A third study demonstrated similar results in two other provinces, Ningxia and Qinghai (Miller et al., 2012). From these studies, which all used data from the studies' randomized controlled trials and collectively involved more than 20,000 students, it can be concluded that anemia should be considered one of the main factors in China's poor rural areas that is leading to gaps in test scores and may ultimately be limiting opportunities for social and economic mobility.

Despite such clear findings, although academics and policy makers agree on the importance of treating micronutrient deficiencies and recognize the effectiveness of treating with supplementation, the government has been reluctant to adopt a policy of passing out vitamins in schools. After each of the studies (discussed in the paragraph above), the research team, as part of their role as policy advisors to the provincial governments in the provinces in which the studies were carried out, reported the study results to officials in the Department of Education as well as to top provincial leaders in Shaanxi and Ningxia. Public records show that provincial leaders acknowledged the reports and understood them (Zhang, 2009; Zhuan, 2010). However, in both cases (that is, in both Shaanxi and Ningxia), in response to the challenge of trying to improve the nutrition of students, instead of treating the students with iron supplements, eggs were chosen to treat the micronutrient deficiencies in the region. Across Shaanxi literally tens of millions of eggs per month were given out, starting in the fall of 2009 (Zhang, 2009). The same thing happened in the following year in Ningxia (Zhuan, 2010). Starting in the fall of 2010, 3 months after the completion of the supplementation study in Ningxia, students in poor rural Ningxia schools began to receive an egg per day. At the national level, in response to a 16 billion RMB school lunch program, one of the most fundamental strategies has been to pass out eggs to students (Ministry of Education, 2012).

Why is it that provincial governments, which state that they want to improve educational performance, in the face of evidence that multiple micronutrient supplements are effective, decide to distribute eggs to their students? There are a number of possible reasons. One answer may be that it is more convenient since eggs can be procured locally. Another reason may be that culturally it is more acceptable to give out eggs, which are thought to be nutritious. In fact, in certain ways, eggs are nutritious (US Department of Agriculture: Agricultural Research Service, 1999). But, the fact remains, while protein-rich and readily available, eggs lack high enough levels of many of the micronutrients that students are deficient in, particularly iron (eggs have only 0.5 mg), the underlying cause of anemia in students in these regions. Is there something about eggs that may be addressing some other nutritional problem, which when given, will result in even better health and higher test scores? Unfortunately (from the view point of understanding the impact of the egg programs), in the case of both Shaanxi and Ningxia provinces, the government chose to distribute eggs to *all* students in the province, a move that made evaluation impossible.

The goal of this paper is to examine the effect of two separate interventions – an egg treatment and a chewable vitamin treatment – on the anemia status and educational performance of fourth-grade students in Gansu Province. We hope such a study will help clarify whether the policy initiatives of educational leaders who are trying to battle malnutrition as a way to improve educational performance are effective, or whether leaders should consider adopting a direct supplementation approach.

To meet this overall goal we have three specific objectives. First, we measure the extent of anemia among students in our sample. Second, we seek to measure the impact of the two interventions on hemoglobin levels and anemia status. Third and finally, we analyze whether the different approaches to improve student health status actually lead to better educational performance.

To meet these objectives, we report on the results of a randomized controlled trial (RCT) that was conducted in 70 elementary schools in 5 rural counties in Gansu Province. The RCT was made up of three stages. First, we conducted a baseline survey in November 2010 and collected data from over 2000 fourth grade students (mostly aged 9 to 12) in the sample schools before any intervention. Second, we implemented two interventions (a six month long chewable vitamin treatment in which students were given a daily chewable vitamin with iron; and a six month long treatment in which students were given a daily cooked egg). These two interventions were given to students in a randomly assigned set of 40 schools, with 20 schools randomly assigned to each intervention. The remaining 30 schools served as a control group and received no intervention. Finally, in June 2011, after the interventions were completed, we conducted an evaluation survey.

According to our baseline survey, 20% of the students in our 70 sample schools had hemoglobin (Hb) levels below 120 g/L, the World Health Organization's anemia cutoff for children who aged 9 to 12 years old (Gleason, Scrimshaw, Kraemer, & Zimmermann, 2007; UNICEF, 2001). Our multivariate results show that when students in the chewable vitamin group were given one chewable vitamin (that contained 5 mg of iron per tablet and 20 other vitamins and minerals) per day for 6 months, their Hb levels rose by 2.5 points more than students in the control, untreated group. The standardized math test scores of students in the chewable vitamin schools also rose slightly. On the other hand, eggs did not significantly affect the student's Hb levels and we found no effect of the egg treatment on students' standardized math test scores.

The rest of this paper is organized as follows. Section 2 explains our methodology, including sampling methods, interventions/experimental arms, data collection (including our key outcome measures—Hb levels and standardized math test scores) and statistical approach. Section 3 reports the descriptive statistics and multivariate results of the analysis that studies the impact of the two interventions (chewable vitamins and eggs) on student Hb levels. Section 4 covers the descriptive statistics and multivariate results of the analysis that examines the impact of the two interventions on student standardized math test scores. Section 5 concludes.

2. Methodology

The objective of our project was to assess and compare the effects of two interventions (chewable vitamins and eggs) using a cluster, randomized controlled trial (RCT) design at the school level. The health and educational outcomes that we analyze are student Hb levels and standardized math test scores. In the next four subsections we review our sampling methods, the interventions, data collection and the statistical approach.

2.1. Sampling methods

The schools in the study were selected from five counties in Gansu Province in China's poor Northwest region. Because of the new egg policies in Shaanxi and Ningxia (discussed above), it would not have been possible to obtain control schools that had not been given eggs (since an egg per day was given to each student in the province). As a result, we chose to work in a set of counties in eastern Gansu. Gansu and Shaanxi/Ningxia are part of China's poor Northwest region and share many of the same features. The rural populations of the provinces are malnourished (Luo et al., 2010, 2011), with low levels of meat consumption and high levels of consumption of starch-based foods (Luo et al., 2009).

To choose the five sample counties we selected a prefecture bordering both Shaanxi and Ningxia Provinces. The prefecture that we chose was Tianshui prefecture. Next we obtained a list of all counties in the prefecture. There were 5 counties that were mostly rural and poor on this list. These were the five counties that form our sample (Table 1).

To choose the sample schools, we conducted a canvass survey by visiting each sample county's bureau of education and obtaining a list of all elementary schools that had at least 200 students. We shortened the list by requiring that of the 200 or more

Table 1
The distribution of sample schools and students.
Source. Authors' survey.

	Number of schools (1)	Number of students in sample schools (2)	Number of students with hemoglobin test (3)	Percentage of students (4)
Full sample	70	2686	1357	100
By County				
Qingshui	10	561	269	20.9
Wushan	12	531	272	19.8
Zhangjia	10	288	143	10.7
Gangu	19	641	333	23.9
Qinan	19	665	337	24.8
By treatment				
1. Chewable vitamin	20	757	381	28.2
2. Egg	20	833	426	31.0
3. Control	30	1096	550	40.8

students, at least 50 of them lived as boarders in the dormitory and ate most of their meals (5 days out of 7) at school. Schools with more than 50 boarding school students represent around 65% of the student population in the rural areas of these sample counties and so can be considered representative of the majority of students in these regions. We used these criteria because in the coming years these types of schools will be the most common in many areas of rural China (Luo et al., 2010).

We found that 446 schools fit these criteria. From this list, we randomly chose 70 schools to comprise our sample. While the sample is mostly representative of eastern Gansu Province, the external validity should cover large areas of Western China as well because Gansu shares many features with other poor areas in the region. In particular, the sample should be fairly representative of poor counties in Shaanxi and Ningxia that participated in the egg-a-day program.

At the time of the baseline, there were 2686 fourth grade students in the 70 sample schools. Although we gave standardized math tests to all of the students in the sample (described below in the data collection subsection—and hereafter called the math sample), power calculations indicated that we did not need such a large sample of students inside each school for the Hb analysis. Because of funding considerations (Hb tests per student are relatively expensive), we randomly chose 50% of the students in the math sample to be included in the Hb test. At the time of the baseline, a total of 1357 students participated in the Hb test (henceforth, the Hb sample). Both samples are representative of students in larger rural elementary schools with boarding facilities in China's Northwest Provinces.

Although the math sample at baseline included 2686 students (1357 in the Hb sample), there was attrition by the end of the study. For various reasons (school transfers, extended absences, etc.) 105 students were lost to follow-up. Of those 105 students, 53 students were in the Hb sample so the final Hb sample included 1304 students. In generating the final math sample, students with invalid tests at either the baseline or evaluation could not be used which led to dropping an additional 301 students excluded from the analysis of math scores so the final math score analysis sample had 2280 students. We checked those students who were missing and found no systematic differences in key control variables. Moreover, the attrition rate was not correlated with the interventions/experimental arms (Table 2, row 3). Fig. 1 shows the flow of participants through the study as well as the attrition count.

We conducted the baseline survey in November 2010 to measure students' Hb levels and standardized math test scores and to collect information about the diets of the students as well as basic demographic information (described below under "Data Collection"). Following the baseline survey, we randomly assigned the 70 schools to one of two intervention arms plus one set of control schools (described in more detail under "Interventions/experimental arms"): 20 schools to an intervention group that received chewable vitamins; 20 schools to an intervention group that received eggs; and 30 schools to a control group that received no treatment. Assignment was done such that the Hb levels were statistically equal across treatment groups. Henceforth, we designate these three types of schools as chewable vitamin schools, egg schools and control schools.

Table 2 shows summary statistics of baseline characteristics of the sample students and their parents. We find that the key health and nutrition outcome variables (Hb levels and standardized math test scores) are balanced across the three experimental arms (rows 1 and 2). By chance, the baseline math test scores for students in chewable vitamin schools are slightly higher than those of students in the control schools (even though the test scores of the students in the egg and control groups are statistically equal—row 3). We also find no statistical difference among the treatment groups in the main control variables (percentage of female students, years of mothers' education, percentage of mothers staying at home, percentage of boarding students, student's age, and percentage of mothers self-employed or working for a wage, percentage of minority students—rows 4 to 9). Since treatment assignment was random, all differences should be simply a matter of chance. Nevertheless, because of these differences (and in order to increase the efficiency of the multivariate analysis), we control for these variables in our regression analysis to remove possible baseline differences.

2.2. Interventions/experimental arms

As discussed above, the RCT design included three experimental arms: a chewable vitamin group, an egg group, and a control group with no intervention. The interventions were designed to be straightforward and easy to monitor. To make sure that the interventions were implemented properly, we worked closely with the principals and homeroom teachers of the chewable vitamin and egg schools. We also provided a small honorarium (100 yuan—about 1 to 2 days salary) to the principals in all schools and the homeroom teachers of the fourth graders in the treatment schools.

Table 2
The distribution of sample schools and students across treatments from baseline survey in November 2010.
Source: Authors' survey.

	All students	Chewable vitamin group	Egg group	Control group	Difference between chewable vitamin and control groups	Difference between egg and control groups
Baseline survey (November 2010)						
Outcomes						
1. Hemoglobin (Hb) level (g/L)	128.8	128.4	128.8	128.9	−0.53 (0.30)	0.03 (0.02)
2. Percentage of students that were anemic (%)	20.3	21.9	16.0	22.5	−0.60 (0.15)	−6.40 (1.36)
3. Math test score (points out of 29)	17.5	18.2	17.2	17.2	1.02 (2.12)**	0.21 (0.05)
4. Percentage of students that were missing (%)	15.1	12.0	14.8	17.5	−5.5 (1.42)	−2.8 (0.67)
Student characteristics						
5. Percentage living in boarding facilities (%)	6.3	4.8	7.7	6.2	−1.37 (1.17)	1.53 (0.66)
6. Student's age (in months)	125.6	126.6	125.6	125.0	1.58 (0.91)	0.67 (0.37)
7. Percentage of female students (%)	46.9	49.2	46.3	45.8	3.48 (1.41)	0.50 (0.19)
Parent characteristics						
8. Mother does not live at home (%)	24.3	25.4	23.8	24.0	1.47 (0.32)	−0.22 (0.07)
9. Mother has off-farm job (%)	47.2	45.1	49.3	47.0	−1.88 (0.46)	2.25 (0.49)
10. Mother's education level (years)	5.1	5.2	4.8	5.1	0.01 (0.02)	−0.32 (0.56)

Note: t values in parentheses; ***, ** and * indicate significant differences from zero at the 1, 5 and 10% levels, respectively.

The chewable vitamins were given directly to the teacher responsible for the fourth grade students in each school (the homeroom teacher) by the research team. Two chewable vitamin deliveries were made per semester: one at the beginning of the semester, and one at the halfway point of the semester. During the homeroom period, which was typically after lunch, teachers passed the chewable vitamins out to the students. On each Friday afternoon, students were given two chewable vitamins to take home for the weekend. During winter break (a three week period) no chewable vitamins were dispensed. The homeroom teachers in all experimental arms were paid 100 yuan per month (an amount equivalent to two days' pay) for their services during the project. Eggs were also distributed in school by the homeroom teachers (in the same way that chewable vitamins were distributed) and an additional subsidy of 50 yuan a week was provided to the school administration to cover cooking costs. The eggs were eaten during the first period of each school day.

About once per month the research team sent out inspectors to undertake unannounced compliance checks in the chewable vitamin schools and egg schools. During these checks the inspectors interviewed the homeroom teachers who were responsible

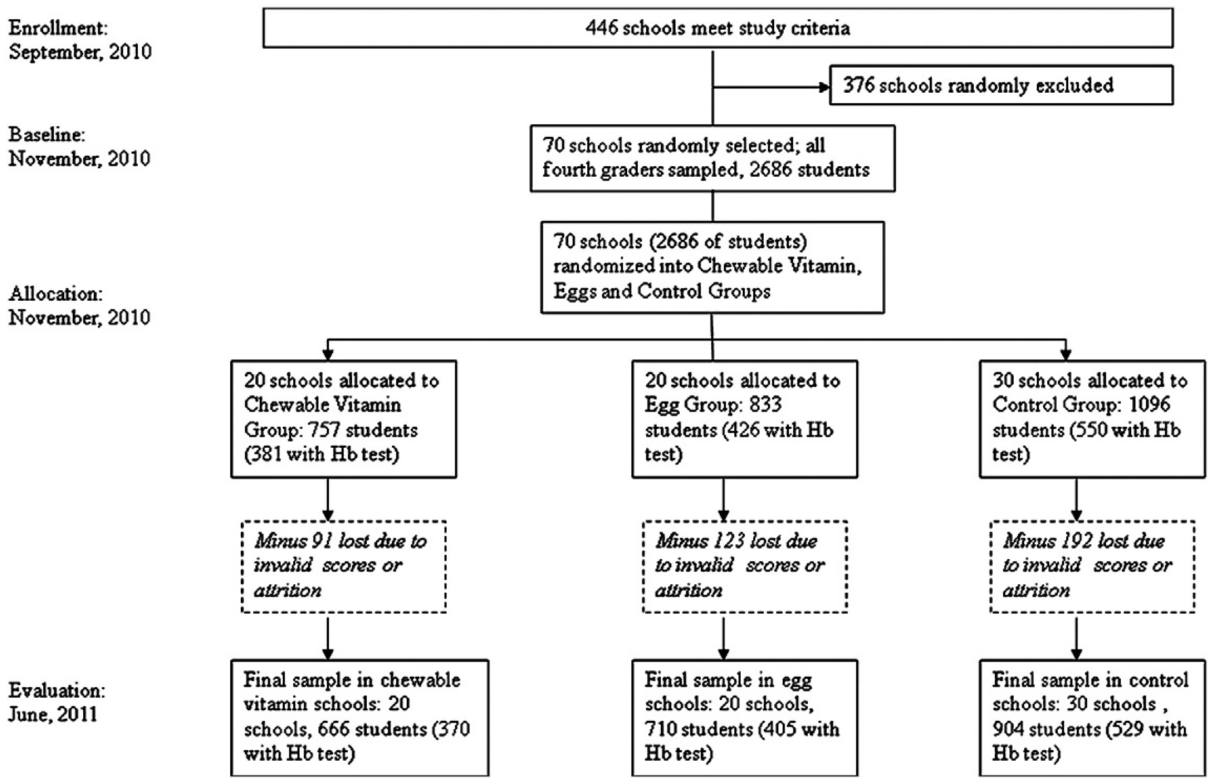

Fig. 1. Flow of participants through the randomized controlled trial.

for dispensing the chewable vitamins and eggs, other teachers who were not part of the intervention (e.g., third or fifth grade teachers), sample students in the chewable vitamin schools and egg schools, and also some students' parents. According to our observations, the compliance level was almost 100%.

During each visit to the treatment schools (both chewable vitamins and eggs schools), the research teams also visited the control schools to check in on the principals and to observe classroom activities of fourth grade students and their homeroom teachers. This was to ensure that any impact found in the treatment schools would be due to the treatments and not to a Hawthorne Effect.

Ethical approval for the study was granted by Stanford University's Institutional Review Board (IRB Protocols 20357 and 20360). The IRB did not allow the use of a placebo in the control group since it was thought that principals and parents might believe students were getting sufficient nutrition and therefore cut back on school lunches or meals at home.

2.3. Data collection

Data for the main health/nutrition outcome variable are based on Hb levels. Hemoglobin levels were measured at baseline in November 2010 and at the end of school year in June 2011. Trained nurses from the School of Medicine of Xi'an Jiaotong University conducted Hb tests onsite using the HemoCue Hb 201+ system. These portable instruments are known to provide rapid, in-the-field measurements of Hb levels with high degrees of accuracy.

Using the measures of Hb levels, we were also able to construct measures of anemia rates. The WHO recommends an anemia cutoff of 115 g/L for children aged 5–11 and a cutoff of 120 g/L for children aged 12–14 (UNICEF, 2001). Given that almost all students in our sample fall in either one of the two age ranges, and that Hb levels borderline for anemia have been shown to affect cognitive functioning (Halterman et al., 2001), we use the 120 g/L cutoff for our analysis, classifying students with Hb levels below 120 g/L as anemic.

The other main outcome variable of our study, standardized math test scores, came from math tests administered by the research team. We created two math tests (one for baseline and one for endline) using questions from the question pools of The Trends in International Mathematics and Science Study (TIMSS) (Mullis, Martin, Gonzalez, & Chrostowski, 2004). In each test students had to finish 29 multiple choice math questions in 30 min. The results of each test gave us one raw math test score (0–29 points) for each student.

We wanted to make sure that the test results were not influenced by any intentional preparation for the tests. Therefore, we made no announcement before the tests and gave no feedback after the tests. We also allowed no extra time for the tests and collected all test instruments after the tests. After the baseline math test we gave no indication to any participants that we would be giving the students another math test towards the end of the school year. Therefore, there was no incentive for anyone (students, teachers or principals) to remember the questions or to teach or learn for the evaluation test.

During the baseline survey we also collected data on students' basic demographic information, including gender, age, boarding status and family structure. We asked the students to fill out a short survey on their own and we supervised the collection of student data in the classroom. Each student also took home a survey to their parents. This survey collected parental information such as age, occupation and levels of education. We collected data about the schools from the principals and data about the teachers from the fourth-grade homeroom teachers.

In June 2011 our trained nurses and the research team visited the 70 sample schools again to collect data on Hb levels, administer the math tests and conduct surveys of students, parents, teachers and principals.

2.4. Statistical approach

We use both descriptive statistics and regression analysis to estimate how Hb levels and standardized math test scores changed in the chewable vitamin and egg schools relative to those changes in the control schools. In both of the analyses of the Hb levels and standardized math test scores, we control for the clustering of the error terms for observations from the same schools.

Our basic model is an ordinary least square (OLS) model in a difference-in-differences setup:

$$\Delta Y_{ij} = a_0 + a_1 * \text{Chewable Vitamin}_j + a_2 * \text{Egg}_j + e_{ij} \quad (1)$$

where ΔY_{ij} is the difference of the outcome variable (either the Hb level or the standardized math test score) between baseline and evaluation surveys for student i in school j. The two independent variables, $\textit{Chewable Vitamin}_j$ and $\textit{Egg}_j$, are dummy variables that equal one if the student is in a chewable vitamin school or an egg school, respectively. The base group for comparison in the regression is the group of students in the control schools. In these equations e_{ij} is an error term that is correlated within schools specific to the cluster-RCT design and a_0, a_1, and a_2 are parameters to be estimated. We then test if the estimates for parameters a_1 and a_2, the average effects of the chewable vitamin and egg treatments, are positive and statistically significant.

In order to account for individual variation at baseline and control for regression to the mean, we included a variable indicating anemia status at baseline for the Hb level regression and the math score at baseline for the standardized math score regression yielding a more robust model:

$$\Delta Y_{ij} = a_0 + a_1 * \text{Chewable Vitamin}_j + a_2 * \text{Egg}_j + a_3 * \text{Baseline Level}_{ij} + e_{ij} \quad (2)$$

where $\textit{Baseline Level}_{ij}$ is either an indicator variable measuring whether or not the child was anemic at baseline (Hb<120 g/L) when the change in hemoglobin levels is being tested or a variable measuring the math score at baseline when the change in standardized math test scores is being tested.

To control for the observable differences between the treatment and control schools at the baseline, we used an adjusted multivariate regression. In this adjusted model, we add to the model in Eq. (2) a number of control variables to control for different student characteristics, including whether the student lives in boarding facilities (yes = 1; no = 0), students' gender (female = 1; male = 0) and students' age (in months) and for different parent characteristics, including mother's level of education (in years of educational attainment), the absence of the mother at home (mother migrates = 1; mother stays at home = 0), and whether the mother has an off-farm job (yes = 1; no = 0). The model that includes all six control variables is our fully adjusted fixed effects model, which can be written as:

$$\Delta Y_{ij} = a_0 + a_1 * \text{Chewable Vitamin}_j + a_2 * \text{Egg}_j + a_3 * \text{Baseline Level}_{ij} + a_4 * \text{Z\_Student}_{ij} + a_5 * \text{Z}_\text{P}\text{arent}_{ij} + e_{ij} \tag{3}$$

where $Z\_Student_{ij}$ and Z_Parent_{ij} are the set of control variables for student and parent characteristics defined in this paragraph.

Finally, we consider food substitution effects that might have differentially occurred in the egg treatment group since parents might think the student is receiving breakfast at school and thus not provide anything at home. However, this substitution effect should mostly be observed in students who are living at home. Thus, we might expect eggs to have a greater impact on students who live in the boarding facilities at school under the assumption that there will not be as significant substitution effects from the parents. To test this hypothesis we include a 4th model that includes an interaction term between the treatments and boarding status:

$$\begin{aligned}\Delta Y_{ij} = a_0 + a_1 * \text{Chewable Vitamin}_j + a_2 * \text{Egg}_j + a_3 * \text{Chewable Vitamin}_j * \text{Boarding}_{ij} + \\ a_4 * \text{Egg}_j * \text{Boarding}_{ij} + a_5 * \text{Baseline Level}_{ij} + a_6 * \text{Z\_Student}_{ij} + a_7 * \text{Z\_Parent}_{ij} + e_{ij}.\end{aligned} \tag{4}$$

In this model the significance of the a_4 coefficient can be used to test whether the eggs intervention had a significantly higher effect on students living in boarding schools.

3. Treatment effects on hemoglobin levels

Although incomes across China have risen in recent years, we find that anemia is still a widespread problem among schoolchildren in the sample schools. Based on our baseline Hb testing, we find that the average Hb level of our student sample was 128.8 g/L (Table 2, row 1, column 1). Hb levels in our sample were normally distributed with a standard deviation of 11.9 g/L. Using the anemia cutoff of 120 g/L, we find that the percentage of students that were anemic was 20.3% (Table 2, row 2, column 1). In other words, one out of five fourth-grade students in our sample is anemic. Because we pre-balanced the allocation of schools to different experimental arms (and as discussed above), all three groups had similar average Hb levels.

When comparing the average hemoglobin levels of all of the students in our sample before (128.8—Table 3, row 1, column 1) and after the intervention (127.6—Table 3, row 1, column 2), we can see that Hb levels declined during the study period by 1.2 g/L (Table 3, row 1, column 3). This may be reflecting a natural seasonal variation rather than being a result of our interventions (because the baseline and endline were done in different seasons of the year) or may simply be noise. In fact, this change in the hemoglobin levels of students in the control schools further reinforces the need for a randomized controlled trial to dissociate the effects of external influences and the intervention. The distribution of the Hb level for the entire sample (including students in both intervention and control schools) before and after the study are shown in Fig. 2A.

Descriptive statistics are consistent with both our previous experiments in the Northwest as well as the international literature showing that providing daily chewable vitamins fortified with iron to students leads to increased Hb levels and a

Table 3
The difference of hemoglobin level and math test score across treatments.
Source: Authors' survey.

	Baseline survey (November 2010)	Evaluation survey (June 2011)	Difference between evaluation and baseline
Hemoglobin (Hb) level (g/L)			
1. Full sample	128.8	127.6	−1.15
By treatment			
2. Chewable vitamin	128.4	128.6	0.22
3. Egg	128.8	128.0	−0.89
4. Control	128.9	126.7	−2.25
Standardized math test score			
5. Full sample	0	0.38	0.38
By treatment			
6. Chewable vitamin	0.17	0.58	0.40*
7. Egg	−0.07	0.28	0.34
8. Control	−0.07	0.31	0.37

Note: ***, ** and * indicate significant differences from control at the 1, 5 and 10 percent levels, respectively; clustered standard deviations are used.

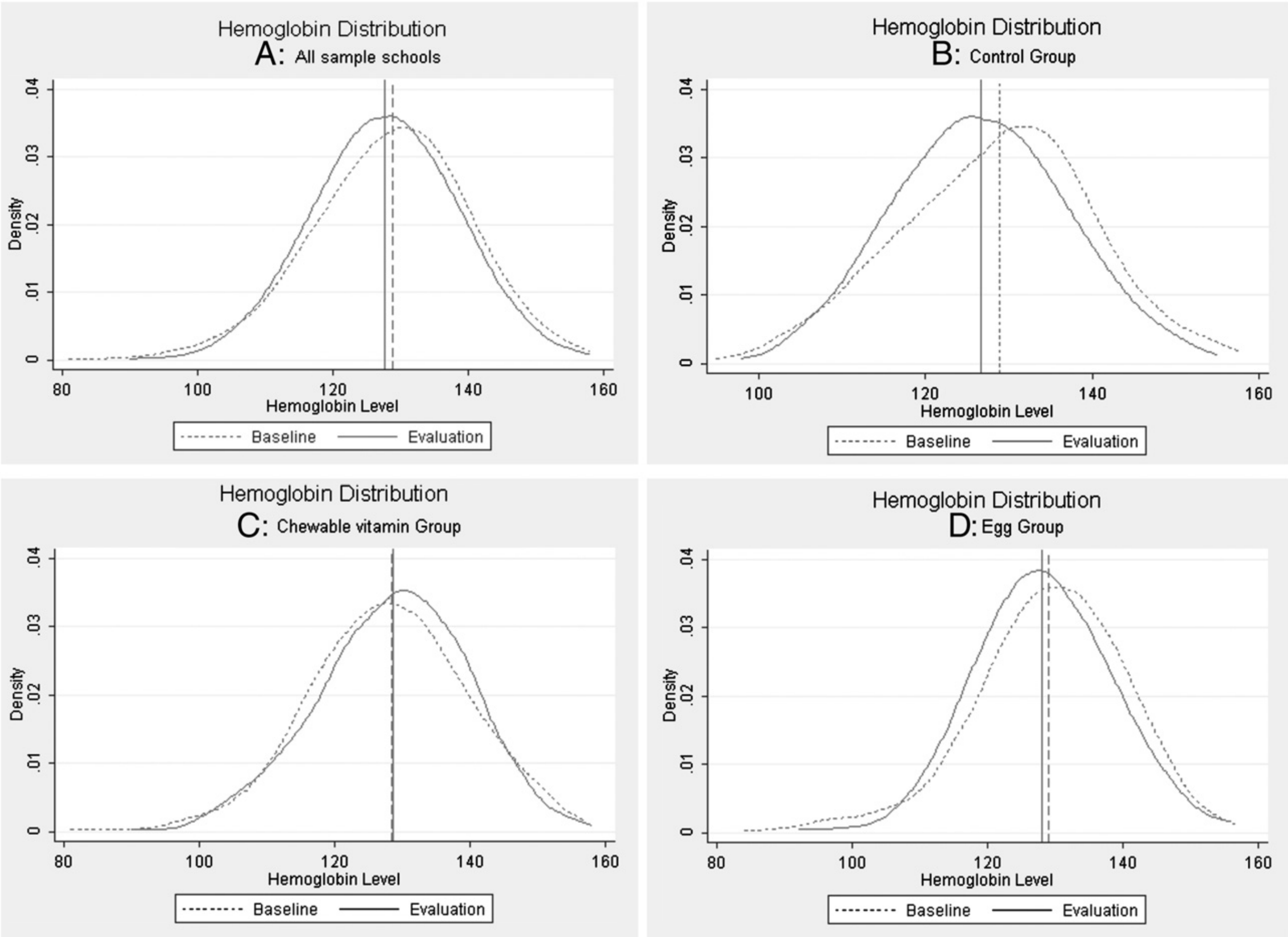

Fig. 2. Distributions of hemoglobin levels before and after the study intervention, November 2010 to June 2011.

reduction in anemia. Table 3 shows that in chewable vitamin schools Hb levels actually rose compared to the decline seen in control schools. The average change in the Hb level in the chewable vitamin schools between November 2010 and June 2011 was 0.22 points. The average change in the control school during the same time period was −2.25 points (Table 3, row 4, column 3). Therefore, while something caused the Hb levels of the students in the control schools to decline, the Hb level of students in chewable vitamin schools actually rose. The difference in the changes in the chewable vitamin schools compared to the changes in the control schools was statistically significant at the 10% level. The changes in the distributions over time for control schools and chewable vitamin schools are shown in Fig. 2B and C respectively.

In contrast, there is less evidence from the descriptive statistics that the egg treatment had an impact on the average student's hemoglobin levels. In fact, average hemoglobin levels fell by 0.89 g/L in the egg schools. Although the decline was not as severe as in the control schools, where Hb levels fell 2.25 g/L, this difference was not statistically significant (unlike the case of the chewable vitamin schools). The shifting distributions of the Hb levels in the control and egg schools are shown in Fig. 2B and D, respectively.

3.1. Multivariate results

The results of the multivariate model largely support the descriptive statistics. As expected, in the simple OLS model (adjusted for clustering) we find that the coefficient on the treatment variable in the hemoglobin level model (2.46, Table 4, row 1, column 1) is nearly the same as the difference between the before-and-after intervention change in the chewable vitamin schools and the change over the same time period in the control schools (0.22 − (−2.25) = 2.47—from Table 3). When we control for baseline level and student and parent characteristics, as in models 2 and 3, the impact of the chewable vitamin treatment on the hemoglobin levels rises (columns 2 and 3). In summary, according to our results, providing fourth grade students with chewable vitamins for a six month period increased their Hb levels from 2.46 to 2.60 g/L. The results in the full model are statistically significant at the 5% level. In other words, the effect of providing fourth grade students with chewable vitamins for a six month period will shift the distribution of the Hb level to the right by over 0.2 standard deviations. This result is comparable to our previous finding in Shaanxi and Ningxia/Qinghai (Luo et al., 2012; Miller et al., 2012; Wong et al., 2012).

Table 4
Effects of chewable vitamin and egg interventions on the change in hemoglobin levels between October 2010 and June 2011 in fourth grade sample schools in Gansu Province.
Data source: Authors' survey.

	Dependent variable: Change in hemoglobin (Hb) level (g/L) before and after intervention			
Independent variables	(1)	(2)	(3)	(4)
Treatment variables				
1. Chewable vitamin (1 = student in vitamin treatment school; 0 = not)	2.46	2.54	2.6	2.51
	1.71*	1.97*	2.00**	2.01**
2. Egg (1 = student in egg treatment school; 0 = not)	1.37	2.12	2.1	2.11
	0.7	1.44	1.43	1.44
3. Chewable vitamin * Lives in boarding facilities				2.2
				0.59
4. Egg * Lives in boarding facilities				−0.05
				0.02
Student characteristics				
5. Anemic at baseline (1 = anemic student; 0 = non- anemic student)		13.22	13.2	13.2
		11.38***	11.55***	11.52***
6. Gender (1 = female; 0 = male)			−1.02	−1.04
			1.89*	1.93
7. Lives in boarding facilities (1 = yes student; 0 = no)			0.59	0.16
			0.45	0.07
8. Student's age (months)			0.02	0.21
			0.71	0.70
Parent characteristics				
9. Mother has off-farm job (1 = yes, 0 = no)			−0.73	−0.71
			1.44	1.41
10. Mother does not live at home (1 = mother migrates; 0 = mother stays at home)			−0.76	−0.77
			1.03	1.05
11. Mother's education level (years)			−0.09	−0.08
			0.89	0.86
Constant	−2.25	−5.22	−6.5	−6.45
	2.16**	5.67***	1.57	1.55
Observations	1304	1304	1304	1304
R-Squared	0.008	0.229	0.236	0.236

Note: ***, ** and * indicate significant differences from zero at the 1, 5 and 10 percent levels, respectively; clustered standard deviations are used.

The coefficient for the egg intervention variable in the simple model is also consistent with the descriptive findings (Table 4, row 2). Our data provides little evidence of any significant effect of the egg intervention on the average student's Hb level in the egg schools. In all of the models that we considered (models 1 to 3—columns 1 to 3 in the table), the egg intervention did not have a statistically significant impact on the change in hemoglobin levels even at a 10% level of statistical significance. Eggs did not lead to rises in hemoglobin levels. Of course, this is expected given the low level of iron in eggs. We found no evidence of a significant interaction between treatment and boarding school status on the change in hemoglobin levels which provides evidence against the hypothesis that students living at home might receive a smaller breakfast or lunch in response to the eggs.

4. Treatment effects on standardized math test scores

One key objective of this paper is to examine whether measures that aim at improving students' health outcomes (increasing Hb levels and reducing anemia rates) in rural China also improve students' educational performance. To achieve this goal, we examine the descriptive data of the standardized math test scores to get a basic understanding of the impacts of chewable vitamins versus eggs. Then, we conduct multivariate analysis using standardized math test scores as our dependent variable for more robust statistical evidence. Even though eggs did not increase Hb levels, it is possible that they still had an effect on standardized math test scores (through some other channel beside the micronutrients that were shown to have increased Hb levels in the chewable vitamin schools).

4.1. Descriptive statistics

During the course of the intervention, math scores across the entire sample rose by 0.38 standard deviations (Table 3, row 5, column 3). This change likely reflects the labors of the academic year and development of the students as the test became easier for them (or alternatively could reflect the fact that endline test was inherently easier than the test at the baseline).

There is descriptive evidence that the chewable vitamin treatment had a positive effect on standardized math scores. The test scores in the chewable vitamin schools rose on average by 0.40 standard deviations (Table 3, row 6, column 3). This rise was greater than that achieved by students in the control schools, who saw an increase in match scores of only 0.34 standard deviations (Table 3, row 8, column 3). In contrast to the increase over controls seen in chewable vitamin schools, standardized math scores in egg schools improved by only 0.34 standard deviations, even less than the increase seen in the control group (0.37—Table 3, row 7, column 3).

4.2. Multivariate results

Although the impact of the interventions on math test scores seen through the descriptive statistics and the basic model (Table 5, row 1–2, column 1) was only modest, once we control for regression to the mean and baseline achievement the coefficient for the chewable vitamin intervention was 0.11 standard deviations while the coefficient for the egg intervention was nearly zero (Table 5, row 1–2, column 2). When further control variables are added (as in model 3), the impact of the chewable vitamin intervention rises to 0.12 standard deviations which is statistically significant at the 10% level. It is important to note that in none of the analyses did we find that the egg intervention had a significant effect on the math scores (Table 5, row 2, column 1–3). In our analysis of the interaction between treatment and boarding school status on the change in math scores we find no significant effect. Thus, the impact of vitamins on improving math scores and the failure of eggs to do the same further argue against the possibility that parents gave less or less nutritious food to students who live at home and received eggs.

5. Conclusion and summary

We have shown that, as in Shaanxi (and other parts of Western China—Luo et al., 2010, 2011), anemia is endemic in rural Gansu elementary schools. The overall anemia rate was greater than 20% when using a hemoglobin cutoff of 120 g/L. Moreover the problem is widespread. Although there was significant variation between counties and schools, the data showed that anemia rates were higher than 10% in over 70% of the schools sampled.

As found in our previous intervention in Shaanxi (Luo et al., 2011), the chewable vitamin intervention in Gansu also produces evidence that demonstrates one of the sources of the achievement gap in rural schools and one possible solution. From the results

Table 5
Effects of chewable vitamin and egg interventions on the Standardized math test score between October 2010 and June 2011 in fourth grade sample schools in Gansu Province.
Data source: Authors' survey.

	Dependent variable: Change in standardized math scores before and after intervention			
Independent variables	(1)	(2)	(3)	(4)
Treatment variables				
1. Chewable vitamin (1 = student in vitamin treatment school; 0 = not)	0.03	0.11	0.12	0.12
	0.58	1.71*	1.93*	1.90*
2. Egg (1 = student in egg treatment school; 0 = not)	−0.03	−0.03	−0.02	−0.03
	0.53	0.55	0.49	0.58
3. Chewable vitamin * Lives in boarding facilities				0.53
				0.27
4. Egg * Lives in boarding facilities				0.09
				0.60
Student characteristics				
5. Standardized math score at baseline		−0.31	−0.32	−.32
		18.12***	18.67***	18.52***
6. Gender (1 = female; 0 = male)			−0.08	−0.08
			2.11**	2.12**
7. Lives in boarding facilities (1 = yes; 0 = no)			−0.06	−0.9
			0.86	0.85
8. Student's age (months)			−0.01	−0.01
			4.23***	4.19***
Parent characteristics				
9. Mother has off-farm job (1 = yes, 0 = no)			0	0.01
			0.14	0.15
10. Mother does not live at home (1 = mother migrates; 0 = mother stays at home)			0	0
			0.05	0.04
11. Mother's education level (years)			0	0
			0.27	0.26
Constant	0.37	0.36	1.07	1.08
	9.71***	10.13***	6.51***	6.37***
Observations	2280	2280	2280	2280
R-Squared	0.001	0.142	0.153	0.153

Note: ***, ** and * indicate significant differences from zero at the 1, 5 and 10 percent levels, respectively; clustered standard deviations are used.

of our randomized controlled trial (RCT) involving over 2500 fourth grade students from 70 randomly selected elementary schools from 5 poor counties in Gansu Province, we found that an intervention that provided over-the-counter chewable vitamins, including iron, to students had a significant impact both on increasing hemoglobin levels and on raising standardized math test scores. In contrast, an intervention that provided daily eggs at school had no significant impact on hemoglobin scores and did not change educational performance.

Given that eggs have very little iron content (only 0.5 mg vs. 5 mg for a chewable vitamin), and given that our previous findings have shown specifically that iron deficiency anemia is endemic across Northwestern China, why did the Shaanxi and Ningxia government officials choose to distribute eggs instead of chewable vitamins (or other iron rich foods such as meat)? One possible explanation is that eggs are traditionally seen as a paragon of a healthy and nutritious food. Another reason may be that eggs can be procured locally while chewable vitamins are not readily available in poor rural areas. Chewable vitamins can be easily ordered in China and shipped to poor areas, but they are not a commonly found item in local supermarkets. Regardless of the reason, however, our results are significant in that they are to our knowledge the first to directly compare a classically nutritious food (like eggs) with chewable vitamin intake. Through our study, we are able to overturn a widely held assumption that nutritious foods are better for health than simple chewable vitamins for a food-secure population.

Our results show that without taking into account the specific micronutrient deficiencies prevalent in a population and the nature of the micronutrient contents of food in a school program, officials may discover that the food that they provide does not have a significant impact on the health or academic performance of the students. Our results suggest that the Shaanxi and Ningxia government programs are misguided in their exclusive focus on increasing nutritional intake through “traditionally” nutritious foods, and that they instead should focus on specific micronutrient deficiencies.

Another hypothesis about why chewable vitamins worked better than eggs is that parental food substitutions not captured by our data may that undermined the egg intervention. If parents and educators know that students are receiving a government provided egg at school, they may cut back on other foods that were originally being served either at home or in the school cafeteria. If this occurred, even if the eggs did benefit student health, the substitution effectively canceled out any net impact, transforming the program into a cash transfer to caregivers (who may or may not choose to invest those funds in the child's development). In contrast, parents and educators may not have reacted to the chewable vitamin intervention, either due to the lack of macronutrients contained in the chewable vitamins, or due to faulty knowledge about the nutritional content of the unassuming-looking tablets.

There are also cost advantages to chewable vitamin distribution as well. The daily cost of a chewable vitamin (at a wholesale price) was about 0.4 yuan per day. The daily cost of an egg was between 0.7 and 0.8 yuan per day. In addition, the time and effort required to procure eggs (on a weekly basis); prepare the eggs (which required fuel and the time of a cook); and distribute eggs (which required about 15 min of the homeroom teacher's time – to get the eggs; pass them out; allow the children to eat them; and clean up) was greater than the time of procuring chewable vitamins (which took effort and time only once during the school year – at the start of the program) and distributing the chewable vitamins (which required only 5 min per day). Overall, these results should encourage China's Ministry of Education (MOE) to look beyond eggs when tackling nutritional problems related to anemia in an educational setting.

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