Erratum

Erratum to “On Integral Inequalities of Hermite-Hadamard Type for s -Geometrically Convex Functions”

Tian-Yu Zhang,¹ Mevlüt Tunç,² Ai-Ping Ji,¹ and Bo-Yan Xi¹

¹ College of Mathematics, Inner Mongolia University for Nationalities, Tongliao City, Inner Mongolia Autonomous Region 028043, China

² Department of Mathematics, Faculty of Science and Arts, Kilis 7 Aralık University, 79000 Kilis, Turkey

Correspondence should be addressed to Tian-Yu Zhang; zhangtianyu7010@126.com

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In [1, Definition 1.9], the concept “ s -geometrically convex function” was introduced.

Making use of [1, Lemma 2.1], Hölder’s integral inequality, and other analytic techniques, some inequalities of Hermite-Hadamard type were established. However, there are some vital errors appeared in main results of the paper [1].

The aim of this paper is to correct these errors and we now start off to correct them.

Correction to Theorem 3.1. Let $f : I \subset \mathbb{R}_+ \rightarrow \mathbb{R}$ be a differentiable function on I° such that $f' \in L([a, b])$ for $0 < a < b < \infty$. If $|f'(x)|^q$ is s -geometrically convex and monotonically decreasing on $[a, b]$ for $q \geq 1$ and $s \in (0, 1]$, then

$$\left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \leq \frac{b-a}{4} \left(\frac{1}{2}\right)^{1-1/q} G_1(s, q; g_1(\alpha), g_2(\alpha)), \quad (1)$$

$$\left| \frac{f(a) + f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \leq \frac{b-a}{4} \left(\frac{1}{2}\right)^{1-1/q} G_1(s, q; g_2(\alpha), g_1(\alpha)), \quad (2)$$

where

$$g_1(\alpha) = \begin{cases} \frac{1}{2}, & \alpha = 1, \\ \frac{\alpha \ln \alpha - \alpha + 1}{\ln^2 \alpha}, & \alpha \neq 1, \end{cases} \quad (3)$$

$$g_2(\alpha) = \begin{cases} \frac{1}{2}, & \alpha = 1, \\ \frac{\alpha - \ln \alpha - 1}{\ln^2 \alpha}, & \alpha \neq 1, \end{cases} \quad \alpha = \left| \frac{f'(b)}{f'(a)} \right|^{sq/2}, \quad (4)$$

$$G_1(s, q; g_1(\alpha), g_2(\alpha))$$

$$= \begin{cases} |f'(a)|^s [g_1(\alpha)]^{1/q} + |f'(a) f'(b)|^{s/2} \times [g_2(\alpha)]^{1/q}, & |f'(a)| \leq 1, \\ |f'(a)| [g_1(\alpha)]^{1/q} + |f'(a)|^{1-s/2} \times |f'(b)|^{s/2} [g_2(\alpha)]^{1/q}, & |f'(b)| \leq 1 \leq |f'(a)|, \\ |f'(a)| |f'(b)|^{1-s} [g_1(\alpha)]^{1/q} + |f'(a) f'(b)|^{1-s/2} \times [g_2(\alpha)]^{1/q}, & 1 \leq |f'(b)|. \end{cases} \quad (5)$$

Proof. Since $|f'|^q$ is s -geometrically convex and monotonically decreasing on $[a, b]$, using Lemma 2.1 and Hölder's inequality gives

$$\begin{aligned}
 & \left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \\
 & \leq \frac{b-a}{4} \int_0^1 \left[t \left| f'\left((1-t)a + t\frac{a+b}{2}\right) \right| \right. \\
 & \quad \left. + (1-t) \left| f'\left((1-t)\frac{a+b}{2} + tb\right) \right| \right] dt \\
 & \leq \frac{b-a}{4} \left\{ \left(\int_0^1 t dt \right)^{1-1/q} \right. \\
 & \quad \times \left[\int_0^1 t |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \right]^{1/q} \\
 & \quad + \left(\int_0^1 (1-t) dt \right)^{1-1/q} \\
 & \quad \times \left[\int_0^1 (1-t) |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \right]^{1/q} \Big\} \\
 & = \frac{b-a}{4} \left(\frac{1}{2} \right)^{1-1/q} \left\{ \left[\int_0^1 t |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \right]^{1/q} \right. \\
 & \quad + \left[\int_0^1 (1-t) |f'(a)|^{q((1-t)/2)^s} \right. \\
 & \quad \times \left. \left. |f'(b)|^{q((1+t)/2)^s} dt \right]^{1/q} \right\}. \tag{6}
 \end{aligned}$$

Let $0 < \mu \leq 1 \leq \eta$ and $0 < s, t \leq 1$. Then

$$\mu^{ts} \leq \mu^{st}, \quad \eta^{ts} \leq \eta^{st+1-s}. \tag{7}$$

When $|f'(a)| \leq 1$, we have

$$\begin{aligned}
 & \int_0^1 t |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \\
 & \leq \int_0^1 t |f'(a)|^{sq((2-t)/2)} |f'(b)|^{sq(t/2)} dt \tag{8} \\
 & = |f'(a)|^{sq} g_1(\alpha), \\
 & \int_0^1 (1-t) |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \\
 & \leq \int_0^1 (1-t) |f'(a)|^{sq((1-t)/2)} |f'(b)|^{sq((1+t)/2)} dt \tag{9} \\
 & = |f'(a) f'(b)|^{sq/2} g_2(\alpha).
 \end{aligned}$$

When $|f'(b)| \leq 1 \leq |f'(a)|$, by (7), we obtain

$$\begin{aligned}
 & \int_0^1 t |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \\
 & \leq \int_0^1 t |f'(a)|^{q[s(2-t)/2+1-s]} |f'(b)|^{sq(t/2)} dt \tag{10} \\
 & = |f'(a)|^q g_1(\alpha),
 \end{aligned}$$

$$\begin{aligned}
 & \int_0^1 (1-t) |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \\
 & \leq \int_0^1 (1-t) |f'(a)|^{q[s(1-t)/2+1-s]} |f'(b)|^{sq((1+t)/2)} dt \tag{11} \\
 & = |f'(a)|^{(1-s/2)q} |f'(b)|^{sq/2} g_2(\alpha).
 \end{aligned}$$

When $1 \leq |f'(b)|$, by (7), we have

$$\begin{aligned}
 & \int_0^1 t |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \\
 & \leq |f'(a)|^q |f'(b)|^{(1-s)q} g_1(\alpha), \tag{12}
 \end{aligned}$$

$$\begin{aligned}
 & \int_0^1 (1-t) |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \\
 & \leq |f'(a) f'(b)|^{(1-s/2)q} g_2(\alpha). \tag{13}
 \end{aligned}$$

Substituting (8) to (13) into (6) yields inequality (1).

Since $|f'|^q$ is s -geometrically convex and monotonically decreasing on $[a, b]$, by Lemma 2.1 and Hölder's inequality, we obtain

$$\begin{aligned}
 & \left| \frac{f(a) + f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \\
 & \leq \frac{b-a}{4} \int_0^1 \left[(1-t) \left| f'\left((1-t)a + t\frac{a+b}{2}\right) \right| \right. \\
 & \quad \left. + t \left| f'\left((1-t)\frac{a+b}{2} + tb\right) \right| \right] dt \\
 & \leq \frac{b-a}{4} \left(\frac{1}{2} \right)^{1-1/q} \left\{ \left[\int_0^1 (1-t) |f'(a)|^{q((2-t)/2)^s} \right. \right. \\
 & \quad \times |f'(b)|^{q(t/2)^s} dt \Big]^{1/q} \\
 & \quad + \left[\int_0^1 t |f'(a)|^{q((1-t)/2)^s} \right. \\
 & \quad \times \left. \left. |f'(b)|^{q((1+t)/2)^s} dt \right]^{1/q} \right\}. \tag{14}
 \end{aligned}$$

When $|f'(a)| \leq 1$, we have

$$\int_0^1 (1-t) |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \leq |f'(a)|^{sq} g_2(\alpha), \quad (15)$$

$$\int_0^1 t |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \leq |f'(a) f'(b)|^{sq/2} g_1(\alpha). \quad (16)$$

When $|f'(b)| \leq 1 \leq |f'(a)|$, by (7), we obtain

$$\int_0^1 (1-t) |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \leq |f'(a)|^q g_2(\alpha), \quad (17)$$

$$\int_0^1 t |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \leq |f'(a)|^{(1-s/2)q} |f'(b)|^{sq/2} g_1(\alpha). \quad (18)$$

When $1 \leq |f'(b)|$, by (7), we have

$$\int_0^1 (1-t) |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \leq |f'(a)|^q |f'(b)|^{(1-s)q} g_2(\alpha), \quad (19)$$

$$\int_0^1 t |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \leq |f'(a) f'(b)|^{(1-s/2)q} g_1(\alpha). \quad (20)$$

Substituting (15) to (20) into (14) leads to inequality (2). Theorem 3.1 is thus proved. $\square$

Correction to Corollary 3.2. Under the conditions of Theorem 3.1,

(1) when $q = 1$,

$$\begin{aligned} & \left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} G_1(s, 1; g_1(\alpha), g_2(\alpha)), \\ & \left| \frac{f(a)+f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} G_1(s, 1; g_2(\alpha), g_1(\alpha)); \end{aligned} \quad (21)$$

(2) when $s = 1$,

$$\begin{aligned} & \left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} \left(\frac{1}{2}\right)^{1-1/q} G_1(1, q; g_1(\alpha), g_2(\alpha)), \\ & \left| \frac{f(a)+f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} \left(\frac{1}{2}\right)^{1-1/q} G_1(1, q; g_2(\alpha), g_1(\alpha)). \end{aligned} \quad (22)$$

Correction to Theorem 3.3. Let $f : I \subset \mathbb{R}_+ \rightarrow \mathbb{R}$ be a differentiable function on I° such that $f' \in L([a, b])$ for $0 < a < b < \infty$. If $|f'(x)|^q$ is s -geometrically convex and monotonically decreasing on $[a, b]$ for $q > 1$ and $s \in (0, 1]$, then

$$\left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \leq \frac{b-a}{4} \left(\frac{q-1}{2q-1}\right)^{1-1/q} G_2(s, q; g_3(\alpha)), \quad (23)$$

$$\left| \frac{f(a)+f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \leq \frac{b-a}{4} \left(\frac{q-1}{2q-1}\right)^{1-1/q} G_2(s, q; g_3(\alpha)), \quad (24)$$

where α is the same as in (4),

$$g_3(\alpha) = \begin{cases} 1, & \alpha = 1, \\ \frac{\alpha-1}{\ln \alpha}, & \alpha \neq 1, \end{cases}$$

$$G_2(s, q; g_3(\alpha))$$

$$= \begin{cases} \left[|f'(a)|^s + |f'(a) f'(b)|^{s/2} \right] [g_3(\alpha)]^{1/q}, & |f'(a)| \leq 1, \\ \left[|f'(a)| + |f'(a)|^{1-s/2} |f'(b)|^{s/2} \right] \times [g_3(\alpha)]^{1/q}, & |f'(b)| \leq 1 \leq |f'(a)|, \\ \left[|f'(a)| |f'(b)|^{1-s} + |f'(a) f'(b)|^{1-s/2} \right] \times [g_3(\alpha)]^{1/q}, & 1 \leq |f'(b)|. \end{cases} \quad (25)$$

Proof. Since $|f'|^q$ is s -geometrically convex and monotonically decreasing on $[a, b]$, by Lemma 2.1 and Hölder's inequality, we have

$$\begin{aligned} & \left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} \left(\frac{q-1}{2q-1} \right)^{1-1/q} \\ & \quad \times \left\{ \left[\int_0^1 |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \right]^{1/q} \right. \\ & \quad \left. + \left[\int_0^1 |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \right]^{1/q} \right\}, \end{aligned} \quad (26)$$

$$\begin{aligned} & \left| \frac{f(a)+f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} \left(\frac{q-1}{2q-1} \right)^{1-1/q} \\ & \quad \times \left\{ \left[\int_0^1 |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \right]^{1/q} \right. \\ & \quad \left. + \left[\int_0^1 |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \right]^{1/q} \right\}. \end{aligned} \quad (27)$$

When $|f'(a)| \leq 1$, we have

$$\begin{aligned} & \int_0^1 |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \\ & \leq |f'(a)|^{sq} g_3(\alpha), \end{aligned} \quad (28)$$

$$\begin{aligned} & \int_0^1 |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \\ & \leq |f'(a) f'(b)|^{sq/2} g_3(\alpha). \end{aligned} \quad (29)$$

When $|f'(b)| \leq 1 \leq |f'(a)|$, by (7), we obtain

$$\int_0^1 |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \leq |f'(a)|^q g_3(\alpha), \quad (30)$$

$$\begin{aligned} & \int_0^1 |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \\ & \leq |f'(a)|^{(1-s/2)q} |f'(b)|^{sq/2} g_3(\alpha). \end{aligned} \quad (31)$$

When $1 \leq |f'(b)|$, by (7), we have

$$\begin{aligned} & \int_0^1 |f'(a)|^{q((2-t)/2)^s} |f'(b)|^{q(t/2)^s} dt \\ & \leq |f'(a)|^q |f'(b)|^{(1-s)q} g_3(\alpha), \end{aligned} \quad (32)$$

$$\begin{aligned} & \int_0^1 |f'(a)|^{q((1-t)/2)^s} |f'(b)|^{q((1+t)/2)^s} dt \\ & \leq |f'(a) f'(b)|^{(1-s/2)q} g_3(\alpha). \end{aligned} \quad (33)$$

Substituting (28) to (33) into (26) and (27) results in inequalities (23) and (24). Theorem 3.3 is thus proved. $\square$

Correction to Corollary 3.4. Under the conditions of Theorem 3.3, when $s = 1$, we have

$$\begin{aligned} & \left| f\left(\frac{a+b}{2}\right) - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} \left(\frac{q-1}{2q-1} \right)^{1-1/q} G_2(1, q; g_3(\alpha)), \end{aligned} \quad (34)$$

$$\begin{aligned} & \left| \frac{f(a)+f(b)}{2} - \frac{1}{b-a} \int_a^b f(x) dx \right| \\ & \leq \frac{b-a}{4} \left(\frac{q-1}{2q-1} \right)^{1-1/q} G_2(1, q; g_3(\alpha)). \end{aligned} \quad (35)$$

Correction to Theorem 4.1. Let $0 < a < b \leq 1$, $0 < s < 1$, and $q \geq 1$. Then

$$\begin{aligned} & 0 < [A(a, b)]^s - [L_s(a, b)]^s \\ & \leq \frac{(b-a)^{1-1/q} s}{8} \left[\frac{4}{s(1-s)q} L(a, b) \right]^{1/q} \\ & \quad \times \left\{ a^{s-1} b^{(s-1)(1-s/2)} \right. \\ & \quad \times \left[L(a^{s(1-s)q/2}, b^{s(1-s)q/2}) - a^{s(1-s)q/2} \right]^{1/q} \\ & \quad + a^{(s-1)(1-s/2)} b^{s-1} \\ & \quad \times \left[b^{s(1-s)q/2} - L(a^{s(1-s)q/2}, b^{s(1-s)q/2}) \right]^{1/q} \Big\}, \end{aligned} \quad (36)$$

$$\begin{aligned} & 0 < [L_s(a, b)]^s - A(a^s, b^s) \\ & \leq \frac{(b-a)^{1-1/q} s}{8} \left[\frac{4}{s(1-s)q} L(a, b) \right]^{1/q} \\ & \quad \times \left\{ a^{s-1} b^{(s-1)(1-s/2)} \right. \end{aligned}$$

$$\begin{aligned} & \times \left[b^{s(1-s)q/2} - L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right) \right]^{1/q} \\ & + a^{(s-1)(1-s/2)} b^{s-1} \\ & \times \left[L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right) - a^{s(1-s)q/2} \right]^{1/q} \Big\}, \end{aligned} \quad (37)$$

where

$$A(a, b) = \frac{a+b}{2}, \quad L(a, b) = \frac{b-a}{\ln b - \ln a}, \quad (38)$$

$$L_p(a, b) = \left[\frac{b^{p+1} - a^{p+1}}{(p+1)(b-a)} \right]^{1/p} \quad (39)$$

for $a \neq b$ and $p \in \mathbb{R}$ with $p \neq 0, -1$ are the arithmetic, logarithmic, and generalized logarithmic means, respectively.

If $q = 1$, then

$$\begin{aligned} 0 & < [A(a, b)]^s - [L_s(a, b)]^s \leq \frac{L(a, b)}{2(1-s)} \\ & \times \left\{ a^{s-1} b^{(s-1)(1-s/2)} \right. \\ & \times \left[L \left(a^{s(1-s)/2}, b^{s(1-s)/2} \right) - a^{s(1-s)/2} \right], \\ & + a^{(s-1)(1-s/2)} b^{s-1} \\ & \times \left[b^{s(1-s)/2} - L \left(a^{s(1-s)/2}, b^{s(1-s)/2} \right) \right] \Big\} \\ 0 & < [L_s(a, b)]^s - A(a^s, b^s) \\ & \leq \frac{L(a, b)}{2(1-s)} \left\{ a^{s-1} b^{(s-1)(1-s/2)} \right. \\ & \times \left[b^{s(1-s)/2} - L \left(a^{s(1-s)/2}, b^{s(1-s)/2} \right) \right] \\ & + a^{(s-1)(1-s/2)} b^{s-1} \\ & \times \left[L \left(a^{s(1-s)/2}, b^{s(1-s)/2} \right) - a^{s(1-s)/2} \right] \Big\}. \end{aligned} \quad (40)$$

Proof. Let $0 < s < 1$, $q \geq 1$, and $f(x) = x^s/s$ for $x \in (0, 1]$. Then the function $|f'(x)|^q$ is s -geometrically convex on $(0, 1]$ for $0 < s < 1$,

$$|f'(a)| = a^{s-1} > b^{s-1} = |f'(b)| \geq 1, \quad (42)$$

and $\alpha = (a/b)^{s(1-s)q/2}$. Therefore,

$$\begin{aligned} g_1(\alpha) &= \frac{2}{s(1-s)qb^{s(1-s)q/2}(\ln b - \ln a)} \\ & \times \left[L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right) - a^{s(1-s)q/2} \right], \end{aligned} \quad (43)$$

$$\begin{aligned} g_2(\alpha) &= \frac{2}{s(1-s)qb^{s(1-s)q/2}(\ln b - \ln a)} \\ & \times \left[b^{s(1-s)q/2} - L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right) \right]. \end{aligned} \quad (44)$$

By Theorem 3.1, Theorem 4.1 is thus proved. $\square$

Correction to Theorem 4.2. Let $0 < a < b \leq 1$, $0 < s < 1$, and $q > 1$. Then

$$\begin{aligned} 0 & < [A(a, b)]^s - [L_s(a, b)]^s \\ & \leq \frac{(b-a)s}{4} \left(\frac{q-1}{2q-1} \right)^{1/q} \\ & \times \left[a^{s-1} b^{(s-1)(1-s/2)} + a^{(s-1)(1-s/2)} b^{s-1} \right] \\ & \times \left[L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right) \right]^{1/q}, \end{aligned} \quad (45)$$

$$\begin{aligned} 0 & < [L_s(a, b)]^s - A(a^s, b^s) \\ & \leq \frac{(b-a)s}{4} \left(\frac{q-1}{2q-1} \right)^{1/q} \\ & \times \left[a^{s-1} b^{(s-1)(1-s/2)} + a^{(s-1)(1-s/2)} b^{s-1} \right] \\ & \times \left[L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right) \right]^{1/q}. \end{aligned} \quad (46)$$

Proof. It is easy to see that

$$g_3(\alpha) = \frac{1}{qb^{s(1-s)q/2}} L \left(a^{s(1-s)q/2}, b^{s(1-s)q/2} \right). \quad (47)$$

Hence, by Theorem 3.3, Theorem 4.2 is thus proved. $\square$

Remark. By the way, all the powers $1 - (3/q)$ which appeared four times in [2, Theorem 4.2 and Corollary 4.2] should be corrected as $3(1 - (1/q))$, respectively.

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