Dear Reviewer #1,

We appreciate your valuable comments on this manuscript, all of which are important and help to improve the manuscript. We agree with your comments and have made changes in our manuscript to reflect the suggestions. Following are point-by-point responses to the comments and concerns, which we hope meet with approval. In our responses, the line number citations refer to the revised version of the manuscript.

**Comments from Reviewer #1**

- **Comment 1:** The paper describes large scale experiments with the Swiss plate geophone. Different transport modes and impact angles of bedload particles were analysed based on video recordings and geophone data.

  The paper is well written and encompasses a sound overview of research on indirect measurement methods. The experiments conducted are precise and the data analysis sound. The number of experiments is however somewhat limited as only one flow condition was analysed.

  The aim of the paper is to investigate how the signal response of the Swiss plate impacted by particles changes with transport mode. Although this aim is adequate, the application of these findings are somewhat missing. The conclusions drawn miss how a continuous transport mode measurement might help to improve bed load data collection. Is future analysis of SPG data improved and does it help to better quantify the grain size distribution?

  Why were saltation length and height or impact velocity not analysed? These are important parameters according to Sklar and Dietrich (2004) in order to estimate the impact velocity. Direct comparison to the recorded impact could have been made. Is it possible to analyse these from the video recordings?

  The number of angles used in the impact experiments is very limited with 45° and 60° only (Table 2). The FEM comparison is not convincing as it does not give similar results. A wider range of experiments would have been useful, also given the fact that 60° impact angle is very high and most of the impacts are likely much lower (e.g. Auel et al. 2017b for supercritical flow).

  Please find below line by line comments to further improve the manuscript.

**Response:** We agree with your comments and some revisions have been made and highlighted in the revised manuscript. Our responses are as follows.

**(1) Regarding to the application or significance of the findings of this study**

① Signal responses of the SPG system generated by bedload impacts can be influenced by a variety of factors, and one of the most crucial may be the complicated motion patterns during the movement of bedload particles. Therefore, it is vital to investigate the SPG response characteristics in various motion modes under the same experimental settings, with a goal to obtain a better understanding of the SPG system. For a given particle size experiment or single-size experiment, the finding of the present study can help to assess the effect of different transport modes on the variability of the SPG signal. However, the results also indicate that the transport mode cannot be precisely identified from the geophone signals in natural field conditions, due to complex interaction of different influencing factors.

② The investigation of this paper shows some new perspectives of the transport characteristics of the bedload particles at the Erlenbach field site, by comparing the analysis data of transport mode from Obernach flume experiments. It indicates that for the transport conditions in the Erlenbach, saltation appears to the dominant mode for *D* larger than about 90 mm, while for *D* smaller than about 90 mm, the larger flow velocity at the Erlenbach could be the reason for less signal response there as compared to the Obernach flume data.

③ The centroid frequency has been found to be less sensitive to varying flow velocities than the maximum packet amplitude, based on controlled flume experiments (Wyss et al. 2016, WRR). In this study, we found that the dependences of centroid frequency on transport mode and impact angle are less than that of maximum amplitude on transport mode and impact angle. Therefore, the centroid frequency appears to be somewhat better suited for particle size identification.

④ The finding may also provide some suggestions for the design of the new filtering method, given the observation (as seen in Figure 10a) that the bedload transport mode has a lower effect on the centroid frequency $f_{\text{centroid}}$ of the SPG signals than the packet amplitude. The new filtering method developed by Nicollier et al. (2021) considers that one important information contained in $f_{\text{centroid}}$ is the particle impact location because high-frequency signals are more rapidly attenuated along the travel path than those with low frequencies. Therefore, generally, packets generated by bedload impacts outside of the Swiss geophone plates have lower $f_{\text{centroid}}$ than those triggered by impacts on a given plate. The fact that $f_{\text{centroid}}$ shows less dependency on transport mode supports our confidence in the filtering method.

### (2) <u>Why were saltation length and height or impact velocity not analysed?</u>

Auel et al. (2017) defined the probability for the rolling mode as the ratio of the travelled distance by a rolling particle to the overall distance determined by the sum of saltation and rolling modes averaged over the numbers of particles travels. Comparably, in our study, the probability is calculated as the number of signal packets generated by particle impacts for each transport mode divided by the total number of effective packets. The two definitions are somewhat different but our experimental observations did not allow to use the same definition as Auel et al. (2017). With regard to impact velocity, the limitation of the video recording and that the set-up was not designed for evaluating its value.

### (3) <u>Limited number of slope angles used in the impact experiments</u>

Significant differences between transport modes (saltation, rolling, and sliding) were observed with regard to the impact angle on the channel bed. Therefore, an inclined chute experiment was conducted in still water to examine the effect of particle impact angle on the signal response of the SPG system (Fig. 1c). Due to the friction, it was difficult for the particles released at the top of the wood chute to keep moving at small chute angles. Hence, the experimental angles in this study were chosen to be 45° and 60° for bedload particles with variable sizes, and no smaller impact angles could be investigated. Therefore, the investigated angles for the chute experiments were rather steep compared to real particle impact angles. Hence FEM simulations were used to analyze the effect of different bedload impact angles, covering a full range of angles (from 0° to 90°). The advantage of the FEM method is that there are not many interfering factors and thus the variables used in the model can be well controlled.

- **Comment 2:** Line 80, 81. Please don't use three headings without text.

**Response:** Agreed. Some content has been added between the headings 2 and 2.1:

"In the methods section, we introduce in turn the controlled experiments including controlled flume experiments and inclined chute experiments, numerical simulations with the FEM model, methods of transport mode analysis and signal processing." (L81-82)

- **Comment 3:** Line 87: Are MPA and JPM data used for further analysis in this paper?

**Response:** The MPA data has been used to measure the transport velocity of bedload, combined with the SPG system, as explained in L285-294 and Appendix B (L575-612). Data recorded by the JPM system was not used in this study.

- **Comment 4:** Line 92: bedload sampled in the field. Where is this bedload from? Is there any relation to a real river. This should be mentioned here. Why $D_{67}$ and $D_{84}$? Please state their values here.

**Response:** Thanks for this valuable advice. The channel bed of the flume facility was reconstructed considering the bed characteristics corresponding to the Navisence field site in Switzerland. The bed roughness is made up by gravel particles that have a size corresponding to $D_{67}$ and $D_{84}$ of the bedload material sampled in the Navisence. The characteristic grain sizes $D_{67}$ and $D_{84}$ were chosen in order to allow all experimental particles to pass smoothly through the reconstructed channel bed with a similar roughness as the natural bed. In addition, the flow velocity and flow depth were adjusted to match with that in the field site. Information on bed characteristics and hydraulic conditions are given in **Table 1.**

**Table 1:** Bed and flow conditions at the Navisence field site and in the flume experiments.

| **Parameters** | **Units** | **Value** |
|---|---|---|
| Bed surface $D_{67}$ | mm | 180 |
| Bed surface $D_{84}$ | mm | 280 |
| Flow depth (Navisence field site) | m | 0.4-0.65 |
| Flow depth over the SPG (flume) | m | 0.54 |
| Flow discharge (flume) | $m^3\ s^{-1}$ | 1.78 |
| Flow discharge (Navisence field site) | $m^3\ s^{-1}$ | 1.2-2.28 |
| Flow velocity (Navisence field site) | $m\ s^{-1}$ | 3-3.5 |
| Flow velocity 0.1 m above the SPG plates (flume) | $m\ s^{-1}$ | 3.30 |
| Flume gradient of the natural bed | % | 4 |
| Flume width | m | 1.02 |
| Froude number (flume) | - | 1.43 |
| Froude number (Navisence field site) | - | 1.39-1.51 |

Some related statement and the table shown above have been added in the revised manuscript (L110-111, L113-114, L125).

- **Comment 5:** Line 107. Please indicate the discharge and the Froude number, the flow is supercritical.

**Response:** Please see the response to the comment 4 (above).

- **Comment 6:** Line 111: The video images in Fig 1b are distorted. Did you apply any correction?

**Response:** The distortion of the video images was caused by the wide-view mode used during recording. However, in the present study, we only focus on the impact instants of particles on the bed. For the dimensions during particles movement, we didn’t apply a correction on the video images.

- **Comment 7:** Line 140: speed. The discussion is a little academic if the word *speed or velocity* should be used as speed is refers to a scalar and velocity to a vector. As you use the term velocity mostly throughout your paper (e.g. caption Fig 2 on the same topic), you should use it consistently.

**Response:** We accept this suggestion and have changed the word “speed” to “velocity” accordingly throughout the manuscript (L152, L321).

- **Comment 8:** Line 125: The chosen angles are rather steep compared to real particle impact angles as e.g. given in Auel et al. 2017b (not cited). Note that these angles are flat due to supercritical flow conditions. Your impact angles might be larger. Please elaborate if 45 and 60° are close to your observations.

**Response:** Thanks for this suggestion. The purpose of the inclined chute experiments can refer to the previous responses above (response to comment 1). The investigated angles in this study were 45° and 60° for natural bedload particles with sizes ranging from 12.3 mm to 95.5 mm and for spherical particles with sizes ranging from 20 mm to 82 mm. It’s true that the chosen angles are rather steep compared to real particle impact angles, and angles of 45° and 60° cannot fully represent actual observed values yet. Hence the FEM simulation is used for non-vertical impacts to investigate the effect of different bedload impact angles, covering a full range of angles (from 0° to 90°) that can be observed in the flume experiments.

Some statements have been added in the text (L137-141).

- **Comment 9:** Line 169: studies have shown.

Line 169: the probability of transport mode. The transport mode has no probability, saltation, rolling or suspension have a probability. Please rewrite.

**Response:** Agreed. This sentence has been rephrased in the manuscript (L194).

- **Comment 10:** Line 171: The choice of Teta_crit is quite crucial as you use it for plotting your results as a function of transport stage T and compare it with many other results taken from Auel et al 2017. Please elaborate in detail how you derived this value. You have a fixed bed. What did Schneider and Shahmohammadi use in their studies? Auel et al. 2017 list a large variety of these values in their Table 3 and state: *most laboratory studies investigated motion of isolated particles moving on top of a bed of similar roughness size, for which* $\theta c = 0.008$ *to 0.01 were determined* (*Fenton and Abbott, 1977; Dancey et al.,2002*).

You also investigated isolated particles over a fixed bed of similar roughness size. Therefore, the choice of 0.03 is too high from my point of view. At least you should perform a sensitivity analysis of your results by varying teta_crit in order to check the effects on your results.

**Response:** Thanks to the reviewer for these careful comments. Indeed, it is quite crucial and difficult to obtain the critical Shields parameter $\Theta_{Critical}$ precisely. Auel et al. (2017) list some values of $\Theta_{\mathrm{Critical}}$ based on a large number of lab studies, indicating that $\Theta_{Critical} = 0.008$ to 0.01 were determined (Fenton and Abbott, 1977; Dancey et al.,2002) in the case of motion of isolated particles moving on top of a bed of similar roughness size. However, $\Theta_{Critical}$ in the present study should have a larger value than 0.008 to 0.01 due to different bed roughness conditions.

**(1) Bed roughness**

For a flat bed, the bed roughness height is given in terms of the Nikuradse roughness height $k_s$ (Camenen et al. 2009). As stated in Camenen et al. (2009), $k_s$ is expected to be in the order of magnitude of the median grain diameter or of some larger grain size percentiles ($k_s = 1$ to 5 times $D_{50}$, $D_{65}$, $D_{84}$, or $D_{90}$ according to the literature) of the bed. In Auel et al. 2017, the equivalent sand roughness height corresponding to $k_s$ has been used, which is determined as $k_s = 0.20$ mm. In present study, $k_s = 180$ mm to 280 mm because the bed surface $D_{67}$ and $D_{84}$ equal to 180 mm to 280 mm, respectively.

Subsequently, an effective roughness ratio $k_s/D$ is given by a value of the effective roughness height $k_s$ divided a characteristic grain size D. In Auel et al. 2017, the effective roughness ratio $k_s/D$ ranges from 0.038 to 0.011. Then the effective roughness ratio $k_s/D$ in our study is determined ranging from 14.63 to 1.05, if $k_s = 180$ mm is taken, which is higher than that in Auel et al. 2017. Studies have shown that $k_s/D$ and the total Shields number $\theta$ show a positive correlation (Camenen et al. 2009), based on a large number of experiments and theories. Consequently, the higher value of $k_s/D$ makes the Shields number $\theta$ of our study greater than that in Auel et al. 2017. Thus, the critical Shields parameter $\Theta_{Critical}$ should also be higher than that given in Auel et al. 2017.

**(2) $\Theta_{Critical}$ determined by the largest particles**

It can be assumed that the maximum particle size used in our experiments (which was transported for the given flow conditions) was close to (but not equal to) the critical size of bedload particles that start moving during the experiments. Therefore, it is possible to estimate $\Theta_{Critical}$ based on the maximum particle size used in our experiments.

$$\Theta_{Critical} < \frac{\overline{\tau_b}}{(\rho_s - \rho) g D_{Max}} = 0.0365$$

where $\overline{\tau_b}$ is the (time-averaged) bed shear stress. According to this calculation, for our experimental conditions $\Theta_{Critical}$ should be smaller than 0.0365.

**(3) Comparation with other field and flume studies**

Considering that the controlled experiments in this study were performed in a flume facility replicating the field site, the critical Shields parameter $\Theta_{Critical}$ should be similar to that of the field site. According to a study for serval mountain streams (Schneider et al. 2015), the median value of the effective shear stress (corresponds to $\Theta_{Critical}$) is determined to be about 0.03 from the main dataset, showing less dependency with the slope of the stream bed.

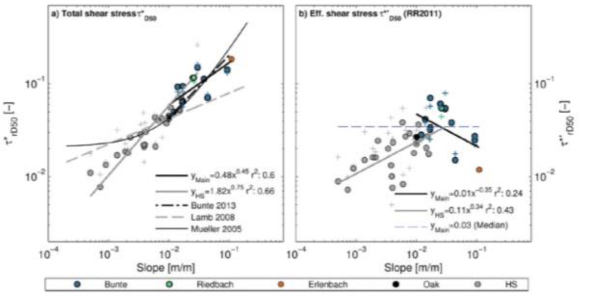


**Figure 3.** Dimensionless reference shear stress ($\tau^*_{rD50}$) related to channel bed slope for (a) the *total* acting bed shear stress $\tau^*_{D50}$ and (b) the reduced *effective* shear stress $\tau^{*'}_{D50}$ (RR2011). Filled circles correspond to $\tau^*_{rD50}$ values from analyzing fractional transport rates (see reference approach section 2.3.2 and Figure 2b. Crosses indicate $\tau^*_{rD50}$ derived from analysis of total dimensionless transport rates. The thick black line was fitted to the Main Data set, and the thick gray line to the HS Data set, for $\tau^*_{rD50}$ derived from the analysis fractional transport rates. In Figure 3a, the empirical relations of *Bunte et al.* [2013], *Lamb et al.* [2008], and *Mueller et al.* [2005] are given. The dashed blue line in Figure 3b corresponds to the median $\tau^*_{rD50}$ from Main Data set.

Figure in Schneider et al. (2015, WRR)

Shahmohammadi et al. (2021) statistically obtained $\Theta_{Critical}$ - Relative Roughness correlation curves from the data of a large number of flume experiments. The Relative Roughness of our experiments ranges from 0.023-0.32, resulting in a median value for the critical Shields parameter of approximately 0.05.

Given the fact that the experimental conditions in this paper are more comparable to those described by Schneider et al. (2015), the critical Shields parameter $\Theta_{Critical}$ in our flume experiments is assumed to be 0.03.

Some statements have been added in the manuscript (L180-191).

- **Comment 11:** Line 157: you mention uniform flow conditions here. This should be mentioned in chapter 2.1.2 already, if the flow is uniform or gradually varied.

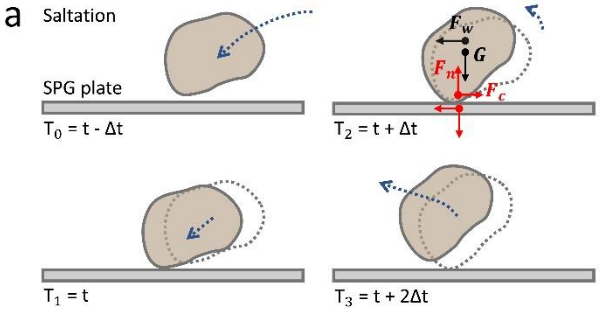
**Response:** This has been added in section 2.1.2 (L111).

- **Comment 12:** Line 176 ff. Chapter 2.3.2. It is not clear for what the description of the forces are used. Fig 4b and c are not explained at all. These forces have to be elaborated in more detail here and used also in the discussion section. See Auel et al 2017b for discussion on vertical and horizontal energy transfer. Else Fig 4 and the corresponding text should be deleted.

**Response:** Thanks for this comment. The reason for showing these forces here is simply to better illustrate the determination of the impact instant (at $T_1$) during the video analysis. These force couples act together on the particle, and finally rotate the particle. This small rotation of the bedload particle occurs immediately after impacting, allowing to determine the impact instant (at $T_1$) from the video frames. Therefore, the forces that are described in Fig. 4 were not measured and cannot be measured under the present experiment set-up.

- **Comment 13:** Line 184: please elaborate more what the vertical support force is? That is not entirely clear for me. Is this connected to the lift force? The lift force is caused by both the flow velocity gradient (Saffman force) and the spinning motion of the particle (Magnus force).
  Please elaborate more on that.

**Response:** In order to better describe how we obtain the time instant when a particle impacts onto the channel bed and the plates during the video analysis, we present three sketches of transport modes of saltation, rolling and sliding, respectively, and also indicate an interaction between the bedload particle and the SPG plate. The forces in these sketches are used only as an aid to illustrate how we observe a few moments when the particles are in contact with the plate or the channel bed. Therefore, the support force here refers to the vertical component force of the plate acting on the contacted particle at this moment. Consequently, we take the instant when the particle undergoes a small rotation as the moment of impact. Hence, we keep the Figure 4 in the manuscript.



We have added some contents in the manuscript (L204-205).

- **Comment 14:** Line 252: I guess you mean $V_P^{EST}$ here instead of $V_P^{CAL}$. Julien and Bounvilay analysed rolling particle velocities. You have mostly saltation in your experiments. Auel et al. 2017 found that particle velocity is only 8.5% lower than flow velocity for saltation in supercritical flows (hence $r_{pw} = 0.915$). Finally which value for $r_{pw}$ did you chose for further analysis as 0.3 to 0.8 is a large variation.

**Response:** Thanks for this valuable comment on the particle velocities. Yes, it should be $V_P^{Est}$ (i.e. the estimated particle velocity in present study). This has been revised in the manuscript (L286).

To compare with other studies, the estimated particle velocities with the $r_{PW}$ ranging from 0.3 to 0.8 are shown in Fig. 12b (the red area). It is true that $V_P^{Est}$ is slower than that given by Auel et al. 2017. However, Auel's estimate that the saltation particles velocity is only 8.5% lower than flow velocity in supercritical flows, is based on his flume experiments, for which the effective roughness ratio $k_s/D$ ranged from 0.038 to 0.011. The effective roughness ratio $k_s/D$ in our experiments ranged from 1.05 to 14.63, and thus there was likely a larger relative difference between particle and flow velocity in our case than in Auel's experiments.

To obtain the bedload velocity more precisely, we calculated the particle velocities $V_P^{Cal}$ using the arrival time difference between the two monitoring systems (SPG and MPA) and corresponding particle travel distances (illustrated by the blue triangles in Fig. 12b). The calculated results showed that the ratio between particle velocity and flow velocity ranges from 0.53 to 0.88.

See line 517 in the revised manuscript.

- **Comment 15:** Line 285: Fig 7. No need to do a semi log plot here, better use a regular Y axis.

**Response:** Agreed. Figure 7 has been revised based on the reviewer's comment (L315).

- **Comment 16:** Line 293, line 308, line 318, Fig 8b, Fig 9b, Fig. 10b. Please elaborate more on the difference between FEM and lab experiments. For me it looks like the results do not match at all. With the FEM I would expect the you reach results close to the still water experiments. How did you calibrate the FEM model?

**Response:** Significant differences between transport modes (saltation, rolling, and sliding) were observed with regard to the impact angle on the channel bed. Therefore, an inclined chute experiment was conducted in still water to examine the effect of particle impact angle on the signal response of the SPG system (Fig. 1c). However, the investigated angles are rather steep compared to more realistic particle impact angles to be expected in field conditions and in our flume experiments, and thus the angles of 45° and 60° may not be very representative. Hence the FEM simulation was used as main method to investigate the effect of different bedload impact angles, covering a full range of angles (from 0° to 90°), on the SPG signal response. The FEM results were compared with the observations from the inclined chute experiment for the cases of 45° and 60°. To give less weight to the chute experiment data covering a very limited range of slope angles, they were removed from Fig 8b, Fig 9b and Fig. 10b, and are now shown in Table 5 (L324-327). While there are discrepancies between the chute experiment data and the FEM results for the values shown in the (old) Fig 8b, Fig 9b and Fig. 10b, the limited change of the characteristic values of the chute experiments with changing slope angle are in qualitative agreement with the FEM results with approximately constant characteristic values over a much larger range of slope angles from 20° to 90°. The discrepancy especially that the values of $Amp_{Max,Pac}$ for the FEM simulations are considerably larger than those from the chute experiments for the impact angles of 45° and 60°. This may be partly because that the impact velocities in the inclined chute experiments were overestimated (L363-365, L462-464).

Before performing the numerical simulations, the FEM model had been calibrated with results obtained from the previous lab experiments (drop tests) with quartz spheres (see below, Chen et al. 2021), which is not shown in the present paper. To make this part more understandable, some details about FEM model have been added in Appendix A (L150-151, L558-574).

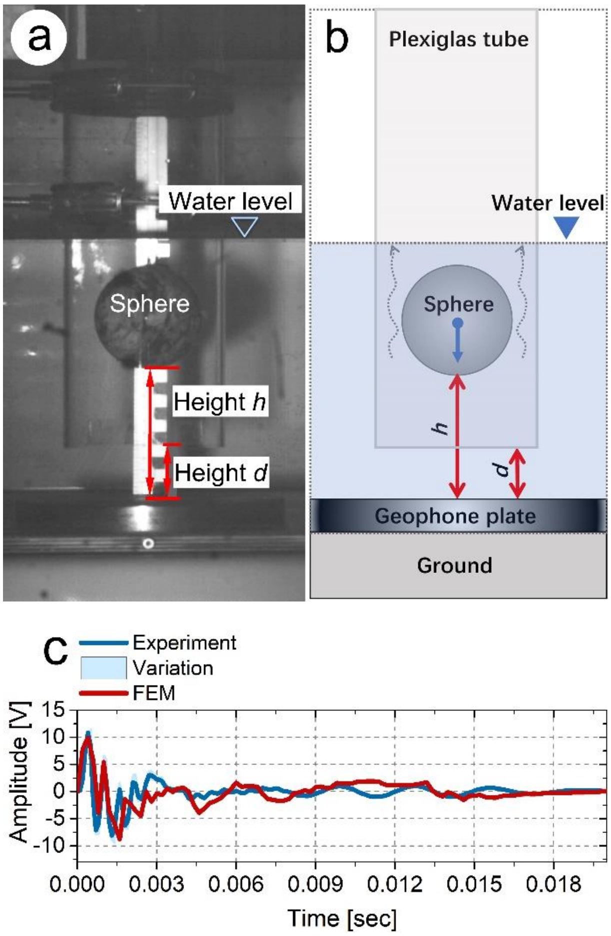


**Figure A1:** (a) Side-view photo (Gaillard, 2018) and (b) sketch (taken from Chen et al. 2021) of the drop-test set-up used in earlier laboratory tests to measure the impact velocity. *h* is the distance between the bottom surface of the sphere and the plate, and *d* is the distance between the bottom of the Plexiglas tube and the plate. The tube protects the sphere from flow turbulences in cases where the set-up is used at field sites. (c) Comparison of the FEM signal and the experimentally generated signal (from the drop test) in the Z-direction (perpendicular to the plate and pointing up), triggered by a single bedload particle (diameter $D$ = 120 mm) impacting on the centric location of the plate with a velocity of 0.777 m/s.

- **Comment 17:** Line 329 ff; Discussion 4.1 should be improved to better understand how these results help to improve the geophone data analysis.

**Response:** Thanks for this comment. This part of discussion has been improved.

- **Comment 18:** Line 330: Please explain what $r_{i,j}$ is good for? For what do you use or need this parameter?

**Response:** $r_{i,j}^{Packet,V\_F}$ is actually the ratio of the packet counts by two different methods. Specifically, $r_{i,j}^{Packet,V\_F}$ is the ratio of the total number of real packets over all transport modes based on the video observations to the real-packet number determined by the filtering method, which can be calculated by

$$r_{i,j}^{Packet,V\_F} = \frac{N_{i,j}^{Packet,V}}{N_{i,j}^{Packet,F}} \text{ (Eq.6 in the manuscript)}$$

where $N_{i,j}^{Packet,V}$ is the total number of real packets for experimental run *i* and grain-size class *j* over transport modes based on the video analysis; $N_{i,j}^{Packet,F}$ is the number of real packets for experimental run *i* and grain-size class *j*, determined by the filtering method.

The purpose is simply to cross-check the results of packet counts and make the data more plausible.

Some related contents are given in the manuscript (L265-270, L374-383).

- **Comment 19:** Line 396. Explain the Hertz theory in a few words please.

**Response:** Agreed. According to the Hertz contact theory (Johnson, 1985; Thorne, 1986), the frequency at which the geophone plate vibrates is controlled by the contacting particle size (Bogen & Møen, 2003; Barrière et al., 2015; Rickenmann, 2017), indicating that the characteristic frequency decreases with increasing contacting particle size.

Some explanations have been added in the text (L442-445).

- **Comment 20:** Line 428: It should be noted here, that Auel et al 2017 did not differ between sliding and rolling. Both modes are included in their rolling mode.

**Response:** Thanks for this comment. This point has been added in the manuscript (L484-485).

- **Comment 21:** Line 436: Difference of estimation of rolling probability of Auel and you is not clear. Please rewrite, how do you obtain your value and what the difference to Auel is.

**Response:** According to Auel et al., 2017, the definition of the probability for the rolling mode is the ratio of the travelled distance by a rolling particle to the overall distance determined by the sum of saltation and rolling modes averaged over the number of particles travels.

Comparably, in our study, the probability for each transport mode is considered as the fraction/ratio that is calculated by the number of signal packets (generated by particle impacts) for each mode to the total number of packets.

This corresponding sentence has been rephrased in the manuscript (L491-494).

- **Comment 22:** Line 445. … Auel et al. (2017) indicated that large particles have a high probability $P_{Rol}$. It is important to note that this is true for similar transport stages T (as T is dependent on friction velocity and particle size).

**Response:** This has been noted in the text (L502).

- **Comment 23:** Line 446: Unclear. Please rephrase. Energy consumption of small particles is larger, that is why they saltate more? By energy consumption you mean energy transfer to the particle?

**Response:** To avoid misunderstanding, this sentence has been deleted in the manuscript.

- **Comment 24:** 447: Proll decreases with large sizes? Please refer to the respective Figure in your results (12a?, In 12a, almost no variation of PR is visible for your saltation results). If Proll decreases, consequently Psal increases. Why should this be the effect of gravity? This result remains unclear. Please define how the 3 modes are related in your analysis (e.g. PRoll = (1-Psal), etc.)

**Response:** Thanks for this comment. We included our experimental data in Fig. 12a (Line 525) by defining the cumulative probabilities $P_{Sli} + P_{Rol} + P_{Sal} = 1$. For the revision, we have first corrected a wrong plotting of our data in Fig. 12. We changed the discussion text as follows: "For the three smallest $T$ values our data show that the sum ($P_{Rol}$ + $P_{Sli}$) values are somewhat smaller whereas $P_{Sli}$ is slightly larger than for other (higher) $T$ values. For small $T$ values the bed shear stress is very close to that of incipient motion of particles, and for more angular or flatter-shaped particles this might have caused a decrease in the $P_{Rol}$ values. Indeed, flatter-shaped particles are more likely to move in the sliding mode according to our video observations. For the four largest $T$ values, the rolling and saltation particles of our experimental data are reasonably consistent with the data of Auel et al. (2017a)."

Some statements have been added in the manuscript (L502-507).

- **Comment 25:** 448f: As transport stage T is a non-dimensional parameter, it should not play a role if your particles are larger.

**Response:** Agreed. We have modified the discussion regarding our experimental data in Fig. 12a (L500-507).

- **Comment 26:** 451: note that Auel et al 2017 did not distinguish between rolling and sliding (see comment line 428).

**Response:** Thanks for this comment. This point has been added in the manuscript (L484-485).

- **Comment 27:** 454: The proposed line between sliding and rolling is interesting. Is this really a fit? Please state R^2.

**Response:** The previous fitted model was obtained by linear regression, with $R^2 = 0.5$. We have removed the line plotted in the Fig 12a (L525).

- **Comment 28:** 455: I agree, that more flow conditions would be needed. Your variation in transport stage stems from different particle sizes but not flow (friction) velocities.
  The meaning of $V_P^{Est}$ is not clear for me. A variation between 30 and 80% is very large. What do you want to show with that?

**Response:** Generally, the value of bedload particle velocity $V_P$ is expected to be less than the water flow velocity $V_W$. The ratio $r_{PW} = V_P/V_W$ is given through a larger number of experiments and variable experimental conditions, ranging from 0.3 to 0.8 for natural particles as suggested by Julien and Bounvilay (2013). Hence the bedload transport velocity can be estimated empirically from the water flow velocity. In this study, we calculate $V_P^{Est}$ only for comparison with other experimental data and our data.

- **Comment 29:** 467: Given that this is a double log plot, the data is not close to Auel et al. 2017. Your power function is 0.32 while it is 0.5 for Auel.

**Response:** Thanks for this comment. It is true that the power function obtained by our flume experiments data is 0.32 while it is 0.5 in Auel et al. (2017). We observe that this variability mainly results due to the smallest value of *T*, demonstrating that the calculated velocity values deviate from the Auel's model (Auel et al. 2017). The reason for this might be that when the particles are getting larger, *T* does not play a major role, as previously stated.

To make it clear, we removed the model line of our study in Fig.12b. Some relevant statements have been excluded in the manuscript (L525, Fig. 12b).

- **Comment 30:** 482 Conclusion.
  Please indicate what would be the benefit of these statements for the geophone data analysis. Does your analysis help to indicate the transport mode with the SPG in the field? This would be the main result of your study. However, your discussion and conclusions do not really reveal if this is possible with your results.

**Response:** Thanks for this comment. Some statements have been added in the text. Also see the responses of the comment 1.

**Additional clarifications**

In addition to the above comments, spelling and grammatical errors pointed out by the reviewer have been corrected in the manuscript.

We look forward to hearing from you in due time regarding our submission and to respond to any further questions and comments you may have.

Sincerely,
The authors of manuscript esurf-2021-72.